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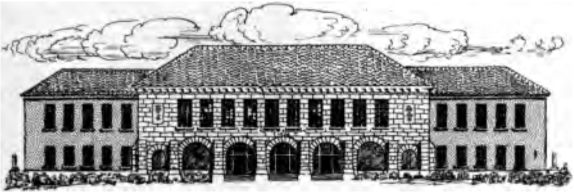

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MACHINE CONSTRUCTION AND DRAWING;

BEING AN INTRODUCTION TO

THE STUDY OF MACHINE CONSTRUCTION

AND TO THE

APPLICATION OF GEOMETRICAL DRAWING FOR
THE REPRESENTATION OF MACHINERY.

BY

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NEW YORK:
G. P. PUTNAM'S SONS,
FOURTH AVENUE AND TWENTY-THIRD STREET.
1873.

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PREFACE.

THE object of this work is to supply the general student, and more especially the engineering student and workman, with an introductory book on the subject of Machine Construction and Drawing. It is unnecessary for us to speak of the importance of a knowledge of the subjects included under this title; we shall, therefore, proceed to state the order and extent of the subjects to be treated of.

Machine or Mechanical Drawing will form the chief part of our work; in conjunction with this we shall consider the form and proportion of certain elementary parts of machinery. To consider the subject fully, it would be necessary to treat of subjects which are beyond the limits of the present work.

A drawing being the representation of some object, in our case a machine or a part of one, it is expected that the student possesses an elementary knowledge of Practical, Plane, and Solid Geometry, since the drawing part of this book will consist of the application of the principles of those subjects to the drawing of machinery. We shall, therefore, assume that he has a knowledge of them; and if he has not, we recommend him to study them simultaneously with this work.

The principal kind of projection used in mechanical drawing is that known as Orthographic or Orthogonal Projection; we shall, therefore, confine ourselves to this kind, laying down such principles as we consider of the greatest importance to the beginner, and upon which the whole will be built up in a systematic manner.

We have endeavoured to arrange the subjects so that they shall form progressive exercises in drawing, and progressive examples of construction. The student, in working out the examples, should draw the figures to a larger scale than those employed for the figures in the book, except where they are drawn full size.

The making of working, finished, and detail drawings will also be considered; these points and some of the various motions will be treated more fully in our Advanced Book.

E. T.

January, 1873.

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MACHINE CONSTRUCTION AND DRAWING.

CHAPTER I.

1. A DRAWING, as the representation of a machine, to be intelligible, should convey a correct idea of the size and proportion of the object represented, and, in most cases, of its several parts; also the various motions which the movable parts are capable of producing.

To make such a drawing of the same size as the machine, it is clear, in many cases, would be almost impossible; we therefore generally make our drawings to a reduced size, or, as it is termed, "*to Scale;*" that is, the drawing may be one-fourth of the size of the object, in which case we say, the drawing is to a scale of one-fourth, or 3 inches = 1 foot. However, to make this point clear, the subject of scales will be treated more fully further on.

2. In drawings of machinery, approximations to the true form of some portions are often employed, and unfortunately too often by those unable to form a just approximation, owing to the want of a knowledge of those principles which are essential for the correct representation of objects. We therefore strongly advise all students to learn first how to draw correctly, so that they may be able to adopt approximations when necessary or advisable.

3. The standard of measurement used in this country is the *foot*, the one-third of the standard *yard*; this is

divided into twelve equal parts, called *inches;* these are subdivided into 8, 16, 32, 64, &c., parts, and termed respectively *eighths, sixteenths, thirty-seconds, sixty-fourths,* &c., denoted by $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, &c., each subdivision being one-half of the preceding. It is usual to denote the size of an object by so many *feet, inches, eighths,* &c., as the case may be; this will be considered in the articles on *scales.*

In some engineering establishments the *decimal rule* is used, wherein the inch is taken as the standard, of which there are ten in each half of the rule, instead of twelve as in the *two-foot rule;* each inch in the decimal rule is divided into ten equal parts, these are again subdivided.

The common *two-foot* being the most used, we shall take our dimensions by means of it. Fig. 1 represents a portion of this rule ; and fig. 2 the decimal rule.

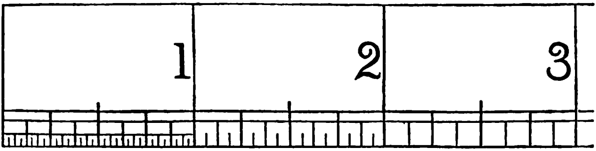

Fig. 1.

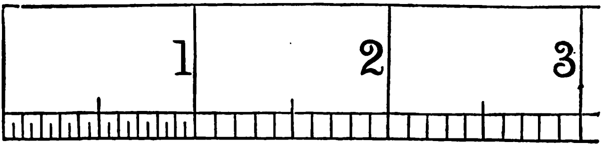

Fig. 2.

CHAPTER II.

4. We will now give the student a few hints on the use of the necessary instruments required for mechanical drawing, assuming that he possesses a drawing-board,

a T-square, two set-squares, drawing-paper, a box of instruments, a scale, india-rubber, and pencils. One of the following sizes of board will be sufficient for present use,—2 ft. 4 in. × 1 ft. 9 in., or 2 ft. × 1 ft. 6 in. The two set-squares should have angles 90°, 60°, and 30°, and 90°, 45°, and 45°, respectively (see figs. 3 and 4).

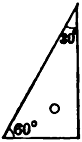

Fig. 3.

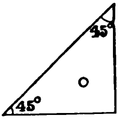

Fig. 4.

5. The drawing-paper for present use may be of a common kind, and fastened down by pins; convenient sizes of sheets are—*Royal*, 25 in. × 20 in., *Imperial*, 30 in. × 21 in. (using half-sheets). When the nature of the drawing demands it, a better kind of paper should be used, the most common being *Double Elephant*, 40in. × 26in.; the smooth is best suited for fine-lining and shading.* The box of instruments should contain at least—dividers, a set of large compasses with lengthening-bar, pen and pencil legs, small pen and pencil bows, a drawing-pen, and a protractor, also a few drawing-pins.

6. The drawing pencils best for ordinary use are, H, H H for fine work, and H B for sketching. Figs. 5 and 6 show how to cut the pencil for using with the squares and bow-pencil (this flat chisel-point will last a considerable time compared with the round point). A small smooth file or sand-paper is useful to rub the pencil upon.

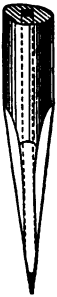

Fig. 5.

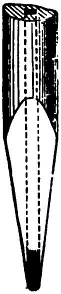

Fig. 6.

As our drawings are to be *inked-in*, the pencil lines should be fine, and made with as little pressure as possible; all lines should be drawn sufficiently long at first, so as not to require producing.

---

* If the drawing is to be coloured or shaded, it should be *stretched* and fixed with glue or gum and not with pins.

7. Lines parallel to the long edges of the drawing-board should be drawn with the T-square, as also lines at right angles to these, if longer than an edge of the set-square (see figs. 7 and 8).

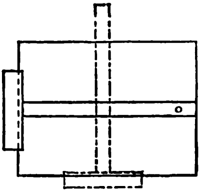

Fig. 7.

Lines not parallel to the sides of the board are best drawn by using the set-squares (see fig. 9), or T and set-squares; and lines at right angles to the one already drawn (whatever may be the position of that line) by reversing the set-square; in fig. 10 *ab* is the line first drawn, *cd* a line at right angles to *ab*.

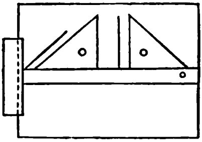

Fig. 8.

Use the india-rubber as little as possible.

8. The following distinguishing lines will be used in this book,—Unbroken lines represent the form of objects, as *ab*, *bc*, &c., in fig 15.; if these lines cannot be seen from the fixed position in which we view them, they are shown by dotted lines, thus, - - - - -, as in figs. 15 and 16; these dotted lines are of the same thickness as the other lines of the object. Lines used to determine the form, or construction lines, are shown as dotted lines,--------------------, but not as thick as the former;* centre lines are shown thus, — · — · —; radius lines are shown thus, ←··········→ dimension lines are shown thus,←------→ Shade or *dark lines*, will be introduced and explained at a later stage.

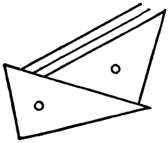

Fig. 9.

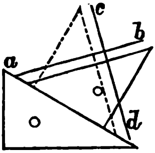

Fig. 10.

The following notation will be used, one accent over a number, as 2′, denotes feet; two accents, as 6″, inches; thus, $1'..0\frac{1}{4}''$ means one foot and a quarter of an inch.

---

* For construction lines the student may use fine continuous lines instead of dotted lines in his pencil drawings.

CHAPTER III.

9. Scales.—In fig. 11 let *a* represent a line two inches long, *b* one an inch long, and *c* one half-an-inch long; then if *b* represents a drawing of the line *a*, the scale would be $\frac{1}{2}$, or 6″ = 1 foot; if *c* represents *a*, then the scale would be $\frac{1}{4}$, or 3″ = 1 foot, and so on.

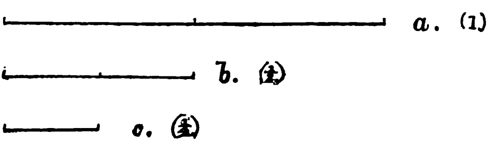

Fig. 11

10. When the scale is denoted by a fraction whose numerator is unity, as $\frac{1}{4}$, the denominator (in this instance 4) denotes how many times larger the object is than the drawing, the term larger to be used in the sense conveyed in the previous and following articles.

If the fraction is of the form $\frac{2}{3}$, the numerator being greater than unity, then we may consider the numerator as expressing how many units of length (feet, inches, &c.) there are in each line of the drawing, the denominator denoting the number of units in the object; for example,—a circle of 3″ diameter if drawn to a scale of $\frac{2}{3}$ would be represented by a circle of 2″ diameter.

11. The reduction in the size of plane objects, when drawn to scale, is to be made in all directions, thus the square, fig. 12, is of one inch side, a drawing of it to a scale of ½ would be a square of ½″ side, as fig. 13; one to a scale of ¼ would be a square of ¼″ side, as fig. 14.

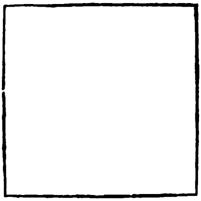

Fig. 12.

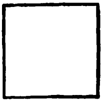

Fig. 13.

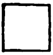

Fig. 14.

In the case of solid bodies, which is the most general one, the reduction in the size of the object, as represented in the drawing, is to be made in every direction,—for example, a cube of 1″ edge, fig. 15, is required to be drawn to a scale of ½, then every line in the drawing must be made one-half the length of the corresponding line of the object. Fig. 16 is a drawing of the cube to a scale of ½, the lines *a′b′*, *b′c′*, *b′d′*, &c., being respectively one-half the length of *ab*, *bc*, *bd*, &c., in fig. 15.

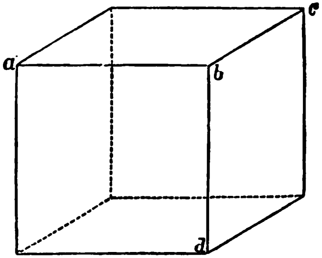

Fig. 15.

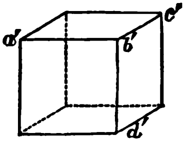

Fig. 16.

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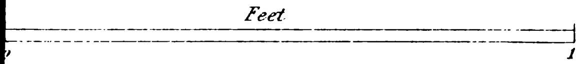

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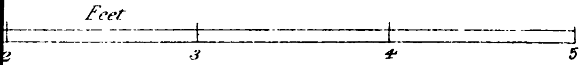

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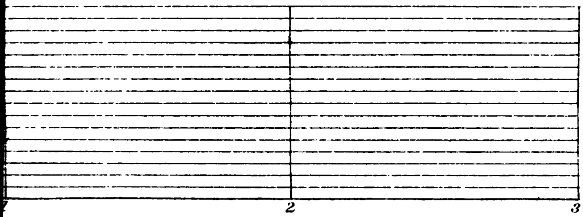

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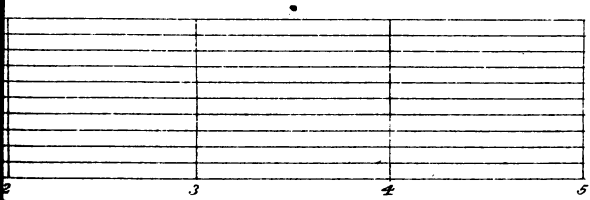

. 20.

12. The scales most frequently used are :—

$\frac{1}{2}$, or 6″ = 1 foot.
$\frac{1}{4}$, or 3″ = 1 foot.
$\frac{1}{6}$, or 2″ = 1 foot.
$\frac{1}{8}$, or $1\frac{1}{2}$″ = 1 foot.
$\frac{1}{12}$, or 1″ = 1 foot.
$\frac{1}{16}$, or $\frac{3}{4}$″ = 1 foot.
$\frac{1}{24}$, or $\frac{1}{2}$″ = 1 foot.
$\frac{1}{32}$, or $\frac{3}{8}$″ = 1 foot.
$\frac{1}{48}$, or $\frac{1}{4}$″ = 1 foot.
$\frac{1}{64}$, or $\frac{3}{16}$″ = 1 foot.
$\frac{1}{96}$, or $\frac{1}{8}$″ = 1 foot.

Fig. 17, Plate I., is an ordinary *plain scale* of $\frac{1}{4}$, or 3″ = 1 foot, showing feet, inches, and quarters of an inch. The left-hand six inches show eighths of an inch.

Fig. 18 is a scale of $\frac{1}{12}$, or 1″ = 1 foot, showing feet, inches, and half-inches. Another kind of scale used is the *diagonal scale.* Fig. 19 shows such a scale of $\frac{1}{8}$, or $1\frac{1}{2}$″ = 1 foot, showing feet, inches, and sixteenths of an inch. This is a good form of scale, and we can obtain a greater number of divisions of any given distance by means of it, than by the more common *plain scale.* It need hardly be remarked that accuracy of construction is absolutely necessary, which remark also applies to all scales. The construction of the diagonal scale, fig. 19, is as follows :—Draw a line, using the T-square, and set off along it distances of $1\frac{1}{2}$″, these will represent feet; or mark off 6″ or 12″, and by repeated bisections obtain the required distance; at the left-hand extremity of this line erect a perpendicular, and along it step sixteen equal distances of any convenient length; through each division draw lines parallel to that first drawn; divide the left-hand foot into twelve equal parts, the scale now shows feet and inches; number the scale as shown; draw a line from No. 11 on the bottom line to No. 16 on the perpendicular line, and from each inch in the bottom line draw lines parallel to 11—16; from each division, 1, 2, 3, &c., on the right of $0b$ erect perpendiculars; the scale is now complete. The distance 0—1 = 1″; between 0—b there are sixteen lines (counting the top one); the diagonal of the rectangle $01ab$ cuts these lines and divides them, so that their lengths increase by $\frac{1}{16}$ of 0—1 (one inch); the lengths of the lines between the diagonal $0a$ and the perpendicular $0b$ are marked on the perpendicular line at 12, counting from the bottom.

The distance between the two dots on the horizontal line marked 8 is $\frac{8}{16}''$ or $\frac{1}{2}''$; between those on line 5, $1'..0\frac{5}{16}''$; on line 13, $2'..7\frac{13}{16}''$. These examples will be sufficient to explain the use of the *diagonal scale.* By the ordinary *plain scale* it would have been impossible to obtain the small division we have in the present case, which is the $\frac{1}{192}$ of $1\frac{1}{2}''$ ($\frac{1}{12} \times \frac{1}{16} = \frac{1}{192}$), that is, the small distance on the horizontal line 1 between $0a$, $0b$, $= \frac{1}{192}$ of 0—12.* Fig. 20 is a *diagonal scale* of $\frac{1}{12}$, showing feet, inches, and tenths of an inch. The distance between the dots on line 9 is $\frac{9}{10}''$ or $\cdot 9''$; on line 7, $3\frac{7}{10}''$ or $3\cdot 7''$; on line 3, $1'..8\frac{3}{10}''$ or $1'..8\cdot 3''$. It is sometimes necessary to make drawings larger than the object, for the purpose of showing more distinctly small intricate motions, &c. We may have drawings $\frac{3}{2}$ ($1\frac{1}{2}$ times), 2, 3, &c., the size of the object. In making scales for such drawings the student will find no difficulty, from what has been said on the subject of scales.

CHAPTER IV.

13. We now pass on to consider the *first lines* to be made in a drawing, whether from a copy, a sketch of a machine, or from the rough sketch of a proposed machine.

First, as to the representation of surfaces. In all cases where a plane figure is symmetrical with respect to a given line, whether the line exists in the figure, or may be considered, for convenience, as existing in it, that line must be drawn first. For example, the circle in fig. 21 is symmetrical with respect to the lines *ab*, *cd*, these lines are to be drawn first, and the point of intersection, *o*, to be taken for the centre of the circle.

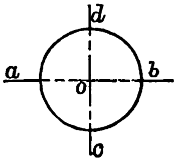

Fig. 21.

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* The distance 0—12 *represents* a foot, but is really only $1\frac{1}{2}''$ long.

In Fig. 22 draw the lines *ab*, *cd*, *ef* before putting in the lines of the object.

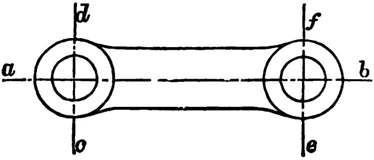
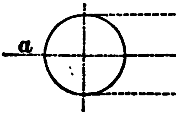


Fig. 22.

Secondly, with respect to solids;—a machine or piece of one. The drawing of any solid object being the *projection* of that object on a plane or planes, the same statement as made for surfaces applies also for solids.



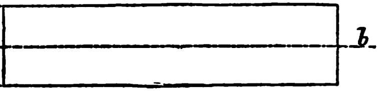


Fig. 23. Fig. 24.

Figs. 23 and 24 are two views of a cylindrical piece of iron, the line *ab* is symmetrical with respect to both figures, and is to be drawn first. Other cases will be noticed as we proceed.

These first lines or *centre lines* should be very fine and distinct;* they are not retained in the drawing when inked-in in the case of *finished drawings* (line, coloured, or shaded); but for *working drawings* they are, and it is usual to ink them in with red or blue colour, as they are most important lines in such drawings.

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* In the examples we shall use a dotted line thus, — · — · —, instead of a fine line, for the sake of distinction and convenience.

CHAPTER V.

14. A drawing of any solid object is the projection of that object on one or more planes, giving one or more views of it. We will state what a projection is, and what are the names given to the different views. In fig. 25 ABCD is the horizontal plane (your drawing-board, for instance); CDEF the vertical plane; let a line *ab* be held perpendicular to the plane ABCD (and therefore parallel to the plane CDEF) at a distance *bc* above it and in front of the plane CDEF. If now the line *ab* is produced to meet the plane ABCD in *c*, the point *c* is the projection of the line *ab*;* from *a*, *b*, draw lines perpendicular to the plane CDEF, meeting it in *a′*, *b′*, then *a′*, *b′* are projections of *a*, *b*; and if *a′*, *b′* be joined, the line *a′b′* is a projection of *ab*. *c* is called a "*plan*," and *a′b′* an "*elevation*" of the line *ab*. The two planes ABCD, CDEF, which are considered to be at right angles in fig. 25, are really one (the plane CDEF being turned down through a right angle), and are represented by the drawing-paper; the line CD in which the planes intersect is the "*ground line*" in our drawings, the line which divides the plan from the elevation.

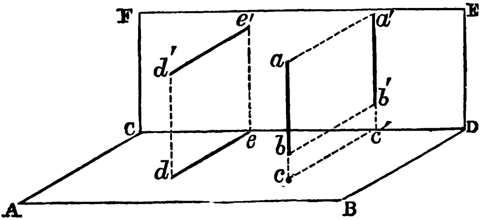

Fig. 25.

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* The point *c* would be termed a "*trace*" in practical solid geometry.

Plate II.

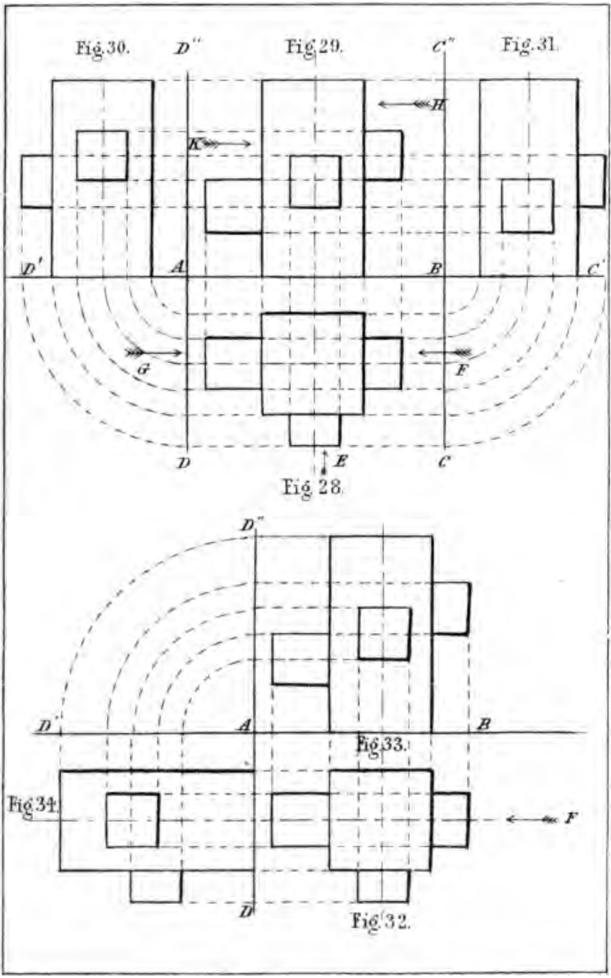


Fig. 30.
D''
Fig. 29.
C''
Fig. 31.
H
K
D'
A
B
C'
G
F
D
E
C
Fig. 28.
D''
D'
A
B
Fig. 33.
Fig. 34.
F
D'
Fig. 32.

A line perpendicular to the vertical plane, and above the horizontal plane, is shown by *d′e′*, *de* is the plan of the line. In figs. 26, 27, the planes are shown by two views, fig. 27 being a front-elevation, and fig. 26 an end-elevation; the lines *ab*, *de* are similarly situated to those in fig. 25. *a′b′* is an elevation of *ab*, *d′e′* an elevation of *de*. The *plan* of *ab* is a point, the *elevation* of *de* is also a point.

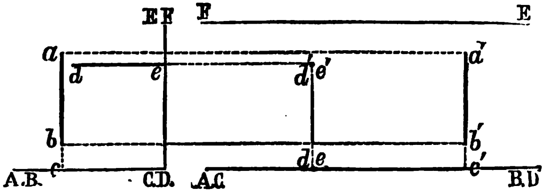


Fig. 26. Fig. 27.

15. To explain the several terms employed for different views of an object, and to show how these views are obtained, we shall use the object shown in figs. 28 to 31, Plate II. The student is requested to pay particular attention to this part of our subject, and thoroughly to understand it before proceeding to the application of the principles here laid down.

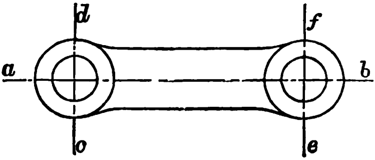
The figure is a prism, whose base is a square upon which it rests, on the horizontal plane (ground); on three faces are placed small prisms differing in length and height, producing an object not symmetrical, as better suited for our purpose. Fig. 28 is a *plan*, that is, a projection on a horizontal plane. Fig. 29 is an *elevation*, that is, a projection on a vertical plane situated at AB; the plane is then turned through a right angle, along the line AB (ground line) as an axis, giving the elevation in the position indicated by fig. 29; the arrow shows the direction of projection, the observer being situated at E. If now we wish to have a view of the object as seen from F, erect a vertical plane at AD, and project an elevation on this plane; now turn the plane into the position AD′, and we have the elevation shown by fig. 30. Fig. 31 is an elevation projected on the plane BC, the observer being at G.

Figs. 30 and 31 may be projected similarly to fig. 29, as shown in figs. 32, 33, 34. Fig. 34 is a projection on the vertical plane AD, which is turned into a *horizontal* position, giving the elevation as shown. The same elevation is obtained in figs. 30 and 34, the only difference being one of position; both methods are employed, convenience generally deciding which is to be adopted; the former, however, is the one chiefly employed. The circular dotted lines shown in the figures need not be put in your drawings after becoming familiar with the principles laid down.

16. The elevations obtained in figs. 30, 31, are the same, both in form and position, as would be obtained if we were supposed to be looking at fig. 29 in the directions H and K respectively, and saw it projected on the vertical planes at AD″, BC″. From these remarks the student will understand that *the position of the object is between himself and its projection;* and when one elevation is projected from another, as fig. 30 from fig. 29, the given elevation and the projection are in the same order as before, calling the given elevation the object; for example, if the observer is at H, fig. 29, looking towards the figure, and wishes to draw the elevation as seen by him in that position, the elevation must be placed in the position occupied by fig. 30; similarly an elevation in the direction K would be placed as fig. 31.

In practice it is sometimes inconvenient, owing to the size of one of the elevations, to follow out this order correctly; in such cases figs. 30 and 31 change places; this should, however, be considered only as an exception. The student is recommended to follow out strictly the order indicated, as it will save him much time and trouble, and make the study of projection more natural to him,

In Fig. 22 draw the lines *ab*, *cd*, *ef* before putting in the lines of the object.



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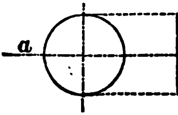

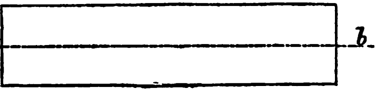

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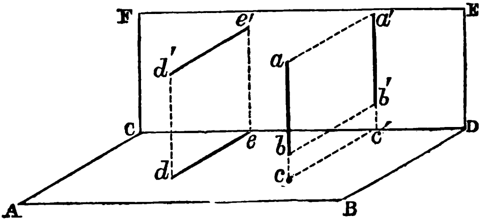

Fig. 25.

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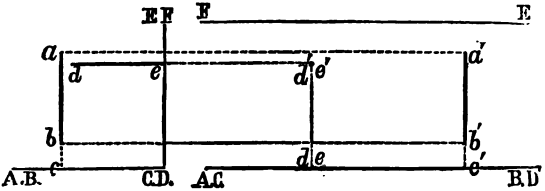

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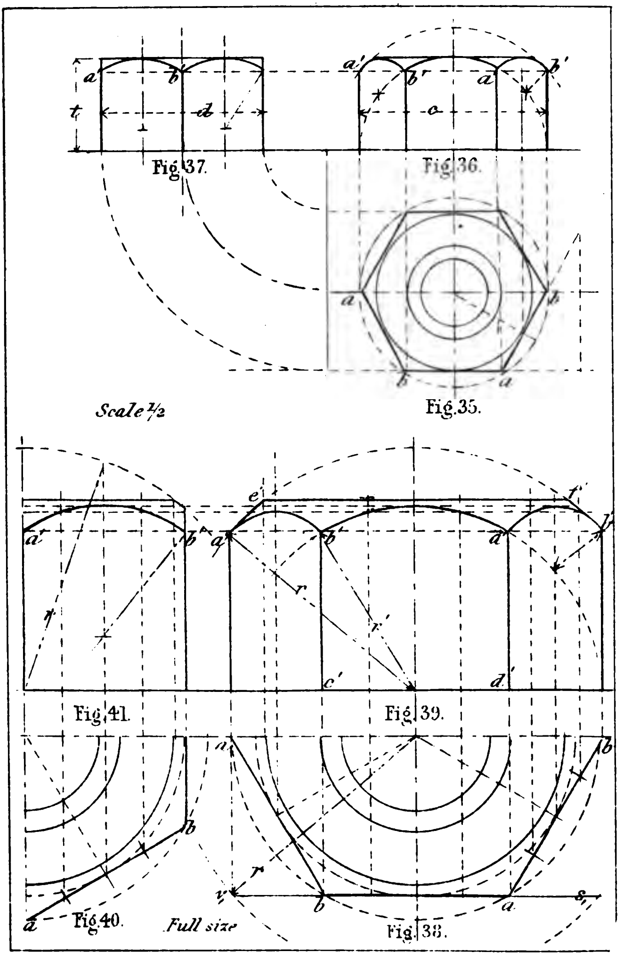
16. The elevations obtained in figs. 30, 31, are the same, both in form and position, as would be obtained if we were supposed to be looking at fig. 29 in the directions H and K respectively, and saw it projected on the vertical planes at AD″, BC″. From these remarks the student will understand that *the position of the object is between himself and its projection;* and when one elevation is projected from another, as fig. 30 from fig. 29, the given elevation and the projection are in the same order as before, calling the given elevation the object; for example, if the observer is at H, fig. 29, looking towards the figure, and wishes to draw the elevation as seen by him in that position, the elevation must be placed in the position occupied by fig. 30; similarly an elevation in the direction K would be placed as fig. 31.

In practice it is sometimes inconvenient, owing to the size of one of the elevations, to follow out this order correctly; in such cases figs. 30 and 31 change places; this should, however, be considered only as an exception. The student is recommended to follow out strictly the order indicated, as it will save him much time and trouble, and make the study of projection more natural to him,

Plate III.


a
b
t
d
Fig. 37.
a'
b'
a
b'
c
Fig. 36.
a
b
b
a
Fig. 35.
Scale ½
e
f'
a'
b'
a'
b'
a'
b'
r
r'
r
c'
d'
Fig. 41.
Fig. 39.
a
b
b
a
r
v
b
a
s
Fig. 40.
Full size
Fig. 38.

and will, at the same time, remove one source of error which he is liable to fall into.

Fig. 28 is a plan; fig. 29 a front-elevation; figs. 30 and 31 end or side-elevations. The term "*view*" is often used instead of "*elevation.*"

CHAPTER VI.

THE examples in this chapter may be used as drawing exercises, the figures to be drawn full or half size.

17. We will now apply the foregoing principles to the representation of various pieces of machinery, &c.

Nuts.—Figs. 35 to 37, Plate III., are elevations and plan of an ordinary *hexagonal nut* for a bolt 1″ diameter, as represented in *scale-drawings;* the elevations are not quite correct, but are good approximations. Fig. 35 is the plan; fig. 36 the front-elevation; fig. 37 an end-elevation. The construction lines clearly indicate how each view is obtained. In figs. 36 and 37 the curves $a'b'$ are considered as arcs of circles; their true form will be considered in the following figures. The greatest and least diameters of the nut are taken from a table of *Whitworth Standards*, a copy of which, with a few additions, is here given (see Table I.). The thickness of the nut (t) is equal to the diameter of the bolt. We shall not give dimensions of nuts in the details to follow, but refer the student to the table given. For ordinary scale drawings, sufficient accuracy will be obtained in drawing nuts if we take the following as a rule for nuts for bolts under 1½″ diameter, viz., make the diameter across the angles = two diameters of the bolt. In figs. 38-41 we show the nut given in the preceding figures drawn full size; in this example the nut is *turned* on the top face and *chamfered;* there are two common ways of chamfering, that forming a *conical outline*, and the one shown, which has a *spherical outline*, the radius of the sphere equalling *r* in figs. 38, 39, 41. By a spherical outline we mean that the chamfered surfaces *a'e'*, *b'f'*, &c., would touch the inner surface of a hollow sphere of radius *r*. All sections of the sphere being circles, that made by the vertical plane $v_1 s_1$, containing the face *a'b'c'd'*, will be a circle of radius *r'* and $= \frac{1}{2}$ the greatest diameter of the nut; the curve *b'a'* is part of this circle. The six faces are all equal, it therefore follows that the curves *a'b'*, *b'a'* are also equal; but as those marked *a'b'* are inclined

TABLE I.

A TABLE OF THE SIZES* OF WHITWORTH STANDARD HEXAGONAL NUTS.

Dia. in in.	Dia. across flats (*d*)		Dia. across angles (*c*)		Dia. in in.	Dia. across flats (*d*)		Dia. across angles (*c*)	
	In Decimals.	To nearest $\frac{1}{32}$ of in.	In Decimals.	To nearest $\frac{1}{32}$ of in.		In Decimals.	To nearest $\frac{1}{32}$ of in.	In Decimals.	To nearest $\frac{1}{32}$ of in.
$\frac{1}{2}$	·9191	$\frac{29}{32}$	1·0612	$1\frac{1}{16}$	$1\frac{1}{2}$	2·4134	$2\frac{13}{32}$	2·7867	$2\frac{25}{32}$
$\frac{5}{8}$	1·101	$1\frac{3}{32}$	1·2713	$1\frac{5}{32}$	$1\frac{3}{4}$	2·7578	$2\frac{3}{4}$	3·1844	$3\frac{3}{16}$
$\frac{3}{4}$	1·3012	$1\frac{5}{16}$	1·5024	$1\frac{1}{2}$	2	3·1491	$3\frac{5}{32}$	3·6362	$3\frac{5}{8}$
$\frac{7}{8}$	1·4788	$1\frac{1}{2}$	1·7075	$1\frac{23}{32}$	$2\frac{1}{4}$	3·546	$3\frac{17}{32}$	4·0945	$4\frac{3}{32}$
1	1·6707	$1\frac{11}{16}$	1·9291	$1\frac{15}{16}$	$2\frac{1}{2}$	3·894	$3\frac{29}{32}$	4·4964	$4\frac{1}{2}$
$1\frac{1}{8}$	1·8605	$1\frac{7}{8}$	2·1483	$2\frac{5}{32}$	$2\frac{3}{4}$	4·181	$4\frac{3}{16}$	4·8278	$4\frac{13}{16}$
$1\frac{1}{4}$	2·0483	$2\frac{1}{16}$	2·3651	$2\frac{3}{8}$	3	4·531	$4\frac{17}{32}$	5·2319	$5\frac{7}{32}$

* There are intermediate sizes which are not enumerated in the Table.

to the vertical plane (at 60° in figs. 38, 39, and 30° in figs. 40, 41), their projections, $a'b'$ in figs. 39, 41, will not be portions of circles, but of ellipses;* their construction is shown in dotted lines. Arcs of circles may be substituted for the portions of ellipses $a'b'$, the error being small.

18. Figs. 42, 43, represent the nut circumscribed by a hemisphere of radius r in former figures; in the plan, fig. 42, are shown two section planes $v_1 s_1$, $v_2 s_2$, each containing a face of the nut, as $v_1 s_1$ in fig. 38. On the left of the centre line in fig. 43 is shown one-half of the face contained in the plane $v_1 s_1$, together with the portion of the sphere cut off by the same plane. On the right of the same figure the face contained in the plane $v_2 s_2$ is shown; the remaining portion of the sphere cut by the plane is distinguished by section lines,† as in the left-hand portion of the figure; the construction lines will explain how to draw fig. 43.

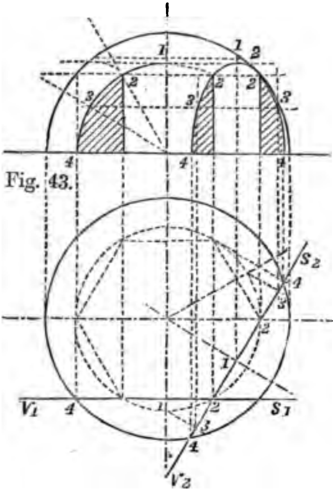


Fig. 43.

Fig. 42.

19. The terms *plan* and *elevation*, as employed for figs. 35-43, and for all details or parts of machinery, are only intended to apply in the cases represented; where we consider the object as a whole; for instance, in a machine we may have *nuts* in various positions, plans, and elevations, in the same elevation of the machine; in that case we speak of the plan or elevation of the machine as a whole, and not with respect to its individual parts. Therefore, when we speak of the plan or elevation of a piece of a machine, we do not assert that that plan or elevation is always a plan or elevation; for what we term a plan in one case, may be an elevation in another.

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* The projection of a circle upon a plane, making an angle with the plane of the circle, is an ellipse.

† We shall distinguish the cut surfaces or sections of objects by diagonal lines, as in fig. 43.

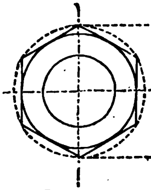

Fig. 46.

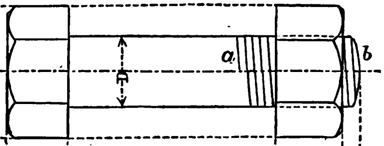

Fig. 45.

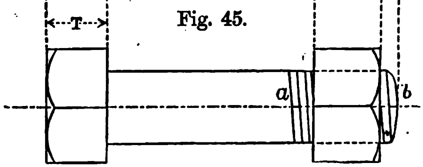

Fig. 44.

20. Bolts.—Figs. 44, 45, and 46 are three views of an ordinary $1\frac{1}{2}''$ bolt with hexagonal head and nut drawn to a scale of $\frac{1}{4}$. Fig. 44 is a plan; fig. 45 a front-elevation; and fig. 46 an end-elevation, showing the screwed end of the bolt and the nut. The screwed part *ab* is not correctly represented in the figures, but is shown as is usual in small scale drawings; we shall consider the true form under the title of screws. The thickness of the *head* $T = \frac{7}{8}$ of the diameter D of the bolt. Bolts are used for the purpose of connecting two or more pieces of material, and are made of various forms. Figs. 47, 48 illustrate a common form, the head *a* is square, the portion *b* next to the head is also square, and fits into a square hole, which prevents its turning round while the nut is being *screwed* on; the diagonal lines on *a* and *b* are used to denote its form (usually only shown in working drawings) when an end-view is not shown.

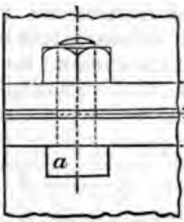

Fig. 47.

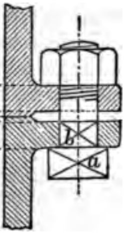

Fig. 48.

Fig. 48 is in section. The figures are drawn to a scale of $\frac{1}{4}$.

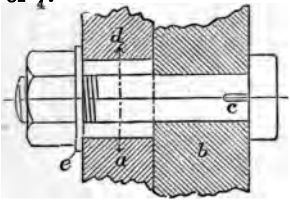

Fig. 49.

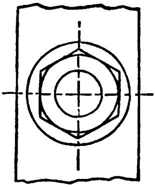

Fig. 50.

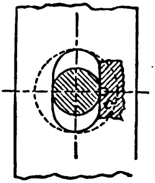

Fig. 51.

21. Figs. 49, 50, 51 represent another mode of connecting two pieces by a bolt. In this example the piece *a* can receive a small change of position in direction *ad*; the bolt is prevented from turning by the *pin* or *key c*; *e* is a *washer*. Fig. 49 is a sectional elevation made by a plane passing through the centre line of fig. 50. We do not show the bolt in *section*, as its shape is shown more clearly by not doing so; this is the usual form adopted. Fig. 50 is an end-elevation; fig. 51 an end-elevation with the bolt in section, showing form of hole in *a* and pin *c*. Such a section is sometimes termed a *cross-section*, and fig. 49 a *longitudinal-section*.

22. Rivets.—Another method of connecting two pieces is given in figs. 52, 53, illustrating a *single riveted lap-joint*, as used for boilers, &c. Rivets are used where the pieces are not required to be separated, and where the nature of the material will permit of the process of riveting. We may say, speaking generally, rivets are used to form a permanent connection, and bolts a temporary one. There are also other considerations besides these which determine the method to be adopted. The *lap* is the distance *a*, the *pitch* *p* is the distance of the rivets apart from centre to centre. Fig. 52 is a front elevation; on the right of the line *bc*, the rivets are shown in section. Fig. 53 is a cross-section through *bc* in fig. 52.

Figs. 54, 55, show two views of the rivets used in the example given in figs. 52, 53, before they are heated and fixed in position; allowance is made in the length *l* for the head *d*, fig. 53.

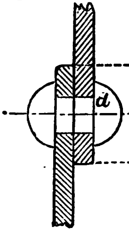

Fig. 53.

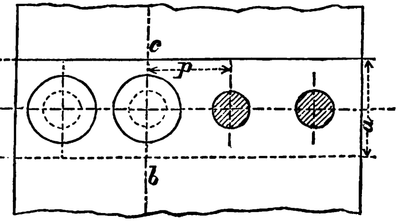

Fig. 52.

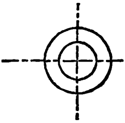

Fig. 54.

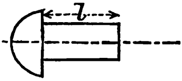

Fig. 55.

23. Shafting.—Shafts are used for the purpose of transmitting motion; they are provided with wheels, pulleys or drums, cams, &c., according to the kind of motion required, and are generally made of a circular cross-section, in some cases the section is square or of other form. The material chiefly used is *wrought-iron; cast-iron* and also *steel* are, however, in some cases employed.

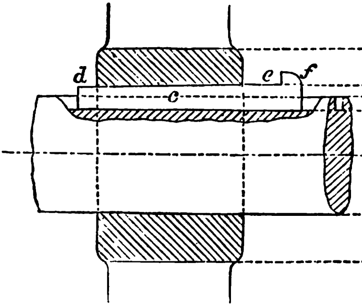

Fig. 56.

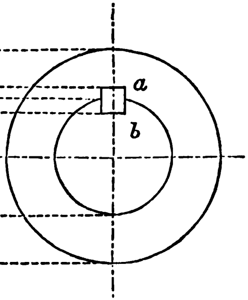

Fig. 57.

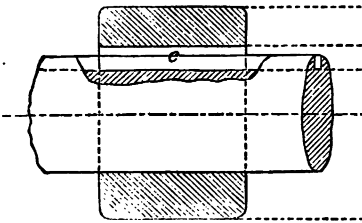

Fig. 58.

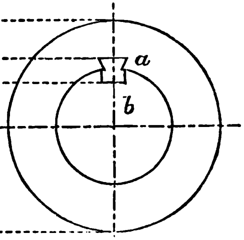

Fig. 59.

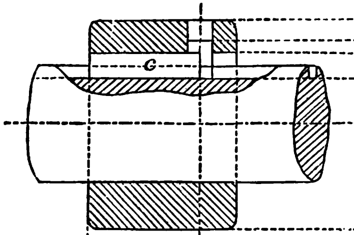

Fig. 60.

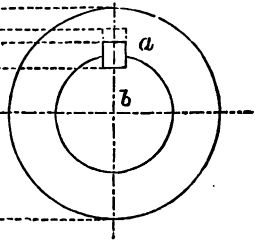

Fig. 61.

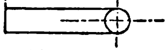

Fig. 62.

Scale ¼.

The relative strength of shafts varies as the cube of their diameters; that is to say, if a shaft of 2 inches diameter is strong enough to transmit four horse-power, then one four inches in diameter, under the same conditions, would transmit thirty-two horse-power.[*]

24. The wheels, pulleys, &c., are firmly connected to the shafts by means of *keys*, which are pieces of metal, generally steel, of a square or rectangular cross-section, and slightly taper in direction *de*, fig. 56, to admit of being driven *home* tight; they should fit easily on the sides of the *key-bed* or *key-way*. In some cases the key is required to slide along the groove in the shaft with the wheel, the key being fixed to the wheel. Figs. 58, 59, illustrate one method of doing this, the key being *dovetailed* into the *boss a* of the wheel. In the example shown in figs. 56, 57, the key has a *head f* to allow of its being *drawn*. Fig. 56 is a sectional elevation, with part of the shaft in section, so as to show the key in full. Fig. 57 is an end-view.

Figs. 58, 59, are similar views of the dovetailed key arrangement; fig. 58, a sectional elevation, fig. 59 an end-view. The boss of the wheel is marked *a*, the shaft *b*, and the key *c*. Scale ¼ for both examples.

25. Another form of sliding key is shown in figs. 60, 61, 62; the key has a head which fits into a circular hole in the boss of the wheel. Fig. 62 is a plan of the key.

26. Fig. 63 is a front-elevation, and fig. 64 an end-elevation, of an ordinary shaft; if the length is such that it cannot be shown in full according to scale, it is *broken off*,[†] as at *ab*, and the length is marked in figures, as shown. Projecting cylindrical pieces *cc*, termed

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[*] If d = dia. of the first shaft (2 in.), h = horse-power transmitted, d' = dia. of the second shaft (4 in.), h' = horse-power transmitted;

$$\text{Then } h : h' :: d^3 : d'^3$$
$$4 : h' :: 8 : 64$$
$$h' = 32$$

[†] This is the usual way of representing parts of machinery, which, for the reason stated, cannot be drawn in full.

collars, are *welded* to the shaft, their object is to prevent the shaft from leaving the *bearings* in direction of its length. The portion between the collars is called the *neck*, and is supported in an accurately fitting surface termed a *bearing*. The length of the neck is generally made 1½ times the diameter of the shaft, for shafts under 6 inches diameter; some makers allow as much as two diameters, and in special cases even more than this.

27. In cases where the fixed collars would prevent the fixing of wheels, pulleys, &c., a *loose collar d* is used. The loose collar is shown in figs. 65 and 66. Fig. 66 is partly in section showing the screw *f*, which fixes the collar to the shaft. Figs. 63, 64, are drawn to a scale of ⅛. Figs. 65, 66, to a scale of ¼.

28. **Bearings.**—By the term bearings is to be understood the *surfaces of contact* between the shaft, or other moving piece, and its support; the form of the bearings depends upon the kind of motion given to the moving piece. The motion of shafting is generally one of *rotation*,* the bearings are therefore surfaces of revolution, as circular cylinders, cones, &c. In figs. 63, 64, the bearings are cylindrical.

If the motion of the shaft or other moving piece is one of straight translation (motion in a straight line), as, for example, the piston-rod and the slide-block of a steam engine, the bearings have a circular, square, triangular, or other straight-lined cross-section, and are perfectly straight in the direction of motion.

A kind of motion made up of the two former is termed *helical* or *screw motion*, the bearings of which must have helical surfaces.

The supporting pieces for the three kinds of motion named are, for rotating pieces, *journals*, *bushes*, and *pivots*; for straight translation, *slides*; and for screws, *nuts*.

29. **Journals** are sometimes formed in the frame of the

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* The term *rotation* is employed to denote the act of turning about an axis.

machine, and generally consist of movable pieces, termed *steps*, made of brass or other alloy. In cases where it is inconvenient or impracticable to adopt this form, *pedestals* or *plummer-blocks* are employed, to which the steps are attached, as illustrated in the drawings of a pedestal, Plate XXIV., figs. 177 to 179.

30. Bushes usually consist of a hollow cylinder of metal, cast-iron, steel, or brass, in which the shaft rotates; they are generally fixed in the frame of the machine. Two common forms of bushes are shown in figs. 67, 68, 69, the drawing of which should present no difficulty to the student. In figs. 67, 68, the bush consists of a plain hollow cylinder *b*, fitting accurately the hole in the frame, and fixed to the latter by means of a screw *s*; *a* is the shaft, *cc* the frame. Half the elevation in fig. 68 is in section. The bush shown in fig. 69, half of which is in section, has a collar *d* on one end, with a screw or screws passing through it, and fixing the bush to the frame; the same letters of reference are used for this example as for the former. Where the wear is considerable it is not advisable to use bushes, unless they can be turned round a little, as they wear, or be replaced readily, as they soon get out of truth; the common plan is to use movable steps, which admit of adjustment to compensate for wear. See drawing of pedestal, Plate XXIV., figs. 177 to 179.

31. Slides.—In figs. 70, 71, is represented a common form of slide; *a* is the fixed surface or *bed*, *b* the sliding piece, *c* is a *strip*, a piece of metal fixed to the sliding piece by the screws *d*, which is acted upon with screws *e*, so as to compensate for wear of the surfaces. Slides are of very common use; among others we may mention the *slide-bars* of steam-engines, the *slide-rests* of lathes, the *cross-slides* of planing machines, &c. Fig. 70 is an elevation showing part of the sliding piece and bed; the latter is in section, as also is the portion of the former, which shows the strip and screws. Fig. 71 is a plan. The figures are drawn to a scale of $\frac{1}{8}$.

32. Nuts.—On Plate VII. is shown the bearing surface of a screw; fig. 87 is an elevation of the screw; fig. 89 a sectional elevation of the bearing or nut, taken through the line SP in fig. 88; fig. 90 shows a section of the screw and nut in contact. The drawing of the screw and nut will be explained later on.

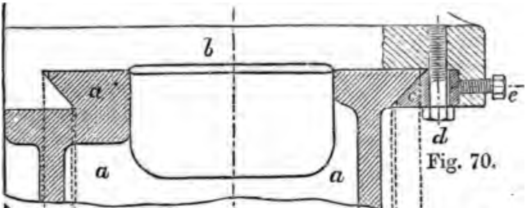


Fig. 70.

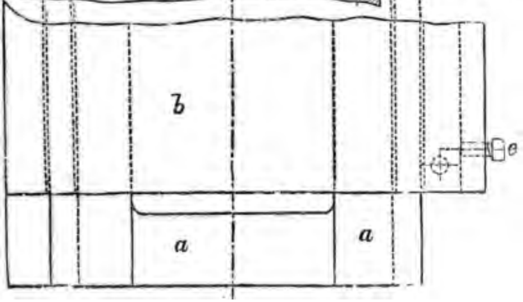


Fig. 71.

33. Couplings.—Shafting is usually made in lengths, whose length varies according to circumstances, for convenience in erecting and mounting, and to allow of disconnecting portions of it. These lengths are connected by couplings. We may divide couplings into two classes; first, those used for shafts, which require disconnecting only at long intervals; and, secondly, where they are being disconnected constantly.

The *box butt*, *box half-lap*, and *face-plate* are the chief kinds used in the first class. In the second class there is a great variety, including *clutches* with from two teeth

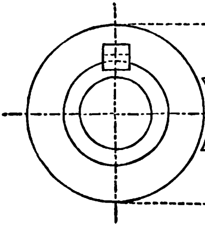


Fig. 72.

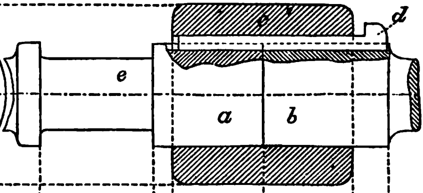
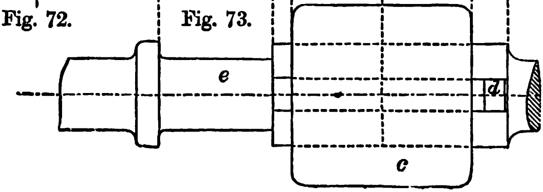


Fig. 73.



Scale ⅛.

Fig. 74.

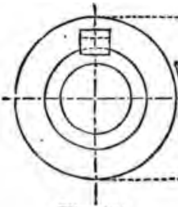


Fig. 75.

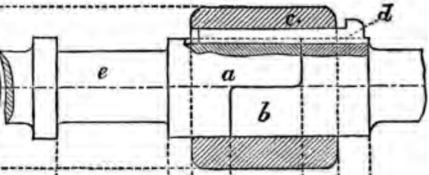
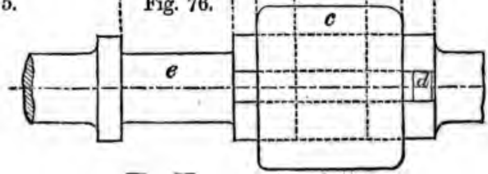


Fig. 76.



Scale ⅛.

Fig. 77.

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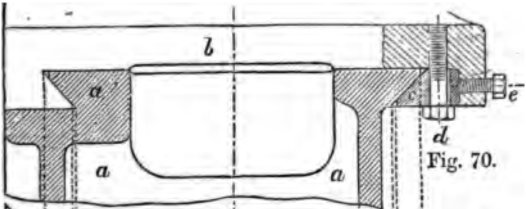

Fig. 70.

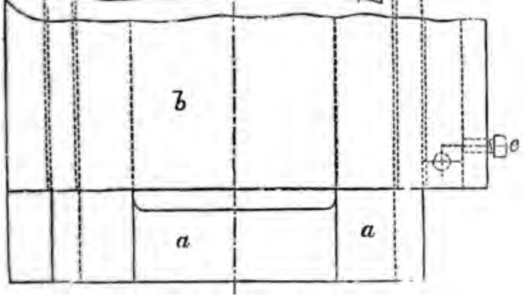

Fig. 71.

33. Couplings.—Shafting is usually made in lengths, whose length varies according to circumstances, for convenience in erecting and mounting, and to allow of disconnecting portions of it. These lengths are connected by couplings. We may divide couplings into two classes; first, those used for shafts, which require disconnecting only at long intervals; and, secondly, where they are being disconnected constantly.

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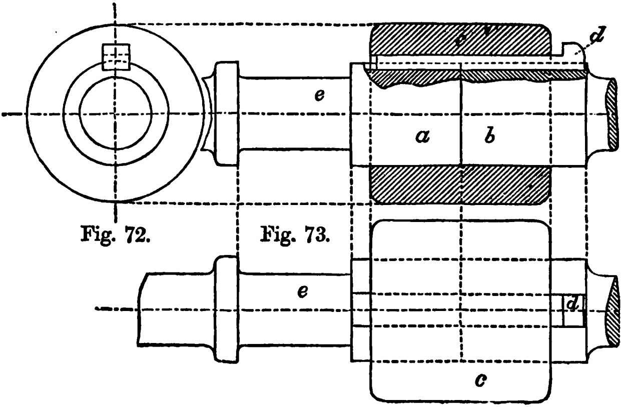

Fig. 72. Fig. 73.

Scale ⅛. Fig. 74.

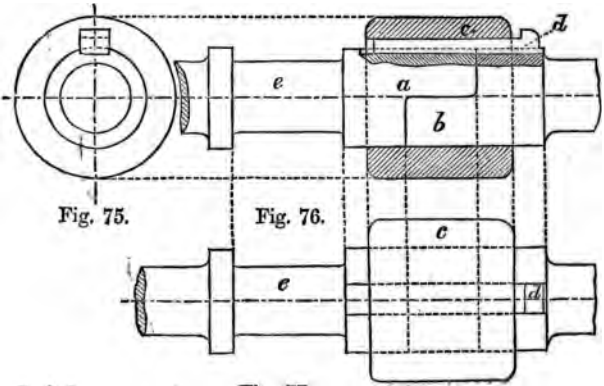

Fig. 75. Fig. 76.

Scale ⅛. Fig. 77.

upwards, *friction cones*, &c. Plate V. shows two forms of the first class, viz., the butt and the half-lap box couplings.

Figs. 72, 73, 74, are views of the butt box coupling; fig. 74 is a plan; fig. 73 an elevation, showing in section the box and portion of the shaft ends, *a* and *b*; fig. 72 is an end-elevation. The two shafts are *swelled out* at the ends so as not to reduce the strength of the shaft by the key-ways, and also that the box may pass over any collars that may be on the shaft. The ends of the shafts and the box are firmly connected by the key *d*. It is usual to place couplings near to the bearings, as shown in the figures; the bearing is on the shaft *a*, and is marked *e*; *c* is the box.

34. The half-lap coupling is represented in figs. 75, 76, 77, which are respectively end-elevation, front-elevation, and plan. The front-elevation is in section, showing the half-lap of the shafts and the connecting key. This coupling was introduced by Mr. Fairbairn.* The following are the proportions given by him:—

Area of coupling - - - = 2 × area of the shaft.
Or, in other words, diameter of coupling - - - - = 1·4142 × area of shaft.
Length of lap - - - = diameter of shaft.
Length of box - - - = 2 × diameter of shaft.
To which may be added outside diameter of box - - - = 2¼ × diameter of shaft.

Figs. 75, 76, 77, represent the coupling adapted for a 3″ shaft, drawn to a scale of ⅛.

35. Helical or Screw Curve.—Figs. 78, 79, Plate VI., represent in front and end-elevation the helical curve, which is traced as follows:—If during the revolution of a cylinder a marker, which moves parallel to the axis of the cylinder and at a uniform rate, traces upon its surface a curve, the curve so traced is called the *helical or screw curve.* The distance moved through by the marker during one revolution of the cylinder is termed the *pitch*, and the direction in which it moves determines whether the

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Now Sir William Fairbairn, Bart.

curve is *right* or *left-hand.* Assuming the cylinder to be turning in the direction of the hands of a watch, as indicated in fig. 78, and the marker to move from right to left (0—16, 0—8 in fig. 79), the curve is *right-handed,* and *left-handed* if *vice versâ.* The curves shown in figs. 78, 79, are right-handed and of the same pitch, but differing in diameter; the pitch is the distance *ab* (0—16). In the example illustrated, the curves are supposed to be fine wires bent to the required form, or the cylinders upon which they are traced are supposed to be transparent, so that the back half of the curve may be seen; the front half of the curve is marked 0—8, the back half 8—16. If the curve were a left-handed one, the portion marked 8—16 would be the. front, and that marked 0—8 the back half.

The length of the curve is equal to the hypothenuse of a right-angled triangle *abc*, fig. 81, having for its base the circumference of the cylinder, fig. 80, and for its height the pitch *ab*, fig. 82. And if the triangle be wound round the cylinder, keeping the base at right angles to the axis, the hypothenuse will assume the curved form shown in figs. 82 and 79, where *ab* = the pitch,

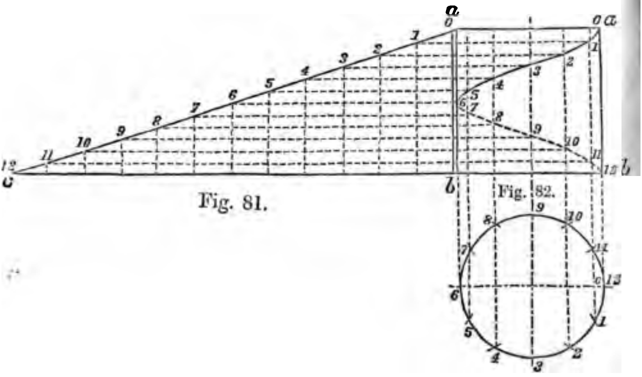

Fig. 81.

Fig. 82.

Fig. 80.

b

3

bc = the circumference of the cylinder, and *ac* = the length of the curve. *ac*, fig. 81, is a *development* of the curve.

36. The drawing of the curve is as follows:—Having the diameter of the cylinder and the pitch of the curve given; for the larger curve, divide the circumference of the circle, fig. 78, into any convenient number of equal parts, divisible by 4, as 12 or 16; and the pitch *ab*, in fig. 79, into the same number of equal parts; in the example we use 16, numbering the points 1, 2, &c., to 16, respectively in both figures. From 16, 1, 2, &c., to 8 (9 to 15 being in the same lines as the former), in fig. 78, draw lines parallel to the axis of the cylinder *cc*, and from 1, 2, &c., to 16, in fig. 79, lines perpendicular to the axis; the intersections of the lines 1—1, 2—2, 3—3, &c., are points in the curve; join these points and the curve is complete. In the top half of fig. 79, between *b*, *d*, is shown a quarter of this larger curve, numbered 4 to 8. In the lower half, between *b*, *d*, is shown a quarter of the smaller curve, numbered 0 to 4, which can be obtained similarly, the construction lines indicating clearly how to project it. In the examples, figs. 78 to 82, we have taken a sufficient number of points to determine the curve with a sufficient degree of accuracy for ordinary purposes; if greater accuracy is required it can be obtained by taking a larger number of points on the circumference of the circle, and the same number between *a* and *b*. It will be noticed the curve is *quickest* between 0—2 and 6—8, figs. 78, 79; intermediate points may be taken between these to determine the curve more accurately.

37. Screws.—Screws are made by cutting helical grooves, of a triangular, square, or other cross-section,* in cylindrical pieces of metal or wood; the ridge or projecting part is termed the *thread*; the *pitch* is the distance between two consecutive threads, measured as described for the helix, Art. 35, page 41. The two common kinds of screws in use, excepting those for wood, are the V or triangular and the square-threaded; the former is chiefly used for *bolts, studs,* and *set-screws;* the latter to transmit motion by means of slides, as in the slides of lathes, planing machines, and other engineering tools, &c.

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* A section made by a plane perpendicular to the direction of the length of the groove.

38. The V-threaded screw is represented on Plate VI., figs. 83 and 84. It is usual to denote the pitch, which varies according to the diameter of the screw, by so many threads per inch in length; in the example shown the screw is $2\frac{1}{4}''$ diameter, and has 4 threads per inch, equivalent to $\frac{1}{4}''$ pitch. In fig. 84 ab is the pitch, which is set off along the centre line, or upon the outline of the cylinder, as shown at 4, 4, a, b; having thus divided the screw for the pitch, draw aa', ab', so that $a'ab'$ contains an angle of 55°, aa', ab' being equally inclined to the axis; from b draw bb' parallel to aa' meeting ab' in b'; b' is the bottom of the groove; draw $b'4'$ parallel to the axis, meeting the centre line of fig. 83 in $4'$; with $C4'$ as a radius, describe the semicircle $4'2'0'$, which will represent the bottom of the groove or thread.

The curves $4b$, $4a$, aa, bb, &c., which form the tops of the threads, and $a'a'$, $b'b'$, &c., which form the bottoms of the threads, are obtained in the same manner as described for the previous figures. The groove $ab'b$, fig. 84, is termed the *space,* and is occupied by a projecting thread in the nut. In this example we have divided the semicircles which form half the end-elevation into 4 equal parts, and, therefore, the pitch into 8 equal parts. As each curve in making a revolution passes through a space ab, half the curve, as seen in fig. 84, will have passed through the space cb, or $\frac{1}{2}ab$, numbered 1, 2, 3, 4. Fig. 85 shows an enlarged section of the thread. In drawing the V we may either draw aa' inclined to the axis at $62\frac{1}{2}°$ $(90°—\frac{55°}{2})$ by setting off the angle by means of a *protractor* from a horizontal line, as the axis, or by placing the protractor at a, perpendicular to the axis, and marking off a line aa' inclined to ae at $27\frac{1}{2}°$ ($\frac{1}{2}$ of 55°), ab' being drawn in a similar manner. Having determined the curves for the top and bottom of the thread, as shown by the dotted lines on the left-hand of fig. 84, the remaining curves may be drawn by means of *templates*, consisting of thin wood or card-board cut to the required form. The templates for the curves *a′a′*, *aa*, &c., fig. 84, are shown in figs. 84*a*, 84*b*. It is much better to make separate templates for the different curves, than to try and make use of the ordinary *moulds* or *curves*. The thread we have described is the "*Whitworth Screw Thread.*"*

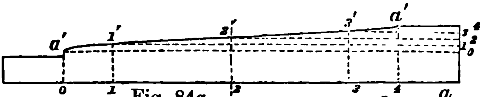

Fig. 84*a*.

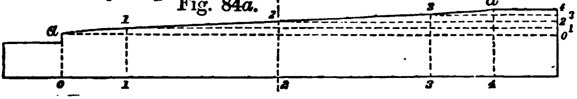

Fig. 84*b*.

In fig. 84 we have shown the thread of the screw with angular top and bottom; this, however, is not quite correct, but for convenience in drawing we may assume it to be so. The Whitworth screw thread has $\frac{1}{6}$ of the depth rounded off at the top and bottom, as shown in fig. 85.

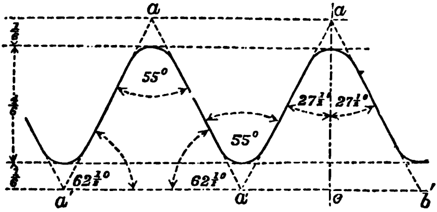

Fig. 85.

39. The following table contains a list of the number of threads per inch in length for screws from $\frac{1}{16}''$ to $6''$ diameter, according to the *Whitworth Standard* : —

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* Introduced by Mr. Joseph Whitworth of Manchester, now Sir Joseph Whitworth, Bart.

TABLE II.

Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.
$\frac{1}{16}$	60	$\frac{5}{8}$	11	$1\frac{3}{4}$	5	$3\frac{1}{2}$	$3\frac{1}{4}$
$\frac{3}{32}$	48	$\frac{11}{16}$	11	$1\frac{7}{8}$	$4\frac{1}{2}$	$3\frac{3}{4}$	3
$\frac{1}{8}$	40	$\frac{3}{4}$	10	2	$4\frac{1}{2}$	4	3
$\frac{5}{32}$	32	$\frac{13}{16}$	10	$2\frac{1}{8}$	$4\frac{1}{2}$	$4\frac{1}{4}$	$2\frac{7}{8}$
$\frac{3}{16}$	24	$\frac{7}{8}$	9	$2\frac{1}{4}$	4	$4\frac{1}{2}$	$2\frac{7}{8}$
$\frac{7}{32}$	24	$\frac{15}{16}$	9	$2\frac{3}{8}$	4	$4\frac{3}{4}$	$2\frac{3}{4}$
$\frac{1}{4}$	20	1	8	$2\frac{1}{2}$	4	5	$2\frac{3}{4}$
$\frac{5}{16}$	18	$1\frac{1}{8}$	7	$2\frac{5}{8}$	4	$5\frac{1}{4}$	$2\frac{5}{8}$
$\frac{3}{8}$	16	$1\frac{1}{4}$	7	$2\frac{3}{4}$	$3\frac{1}{2}$	$5\frac{1}{2}$	$2\frac{5}{8}$
$\frac{7}{16}$	14	$1\frac{3}{8}$	6	$2\frac{7}{8}$	$3\frac{1}{2}$	$5\frac{3}{4}$	$2\frac{1}{2}$
$\frac{1}{2}$	12	$1\frac{1}{2}$	6	3	$3\frac{1}{2}$	6	$2\frac{1}{2}$
$\frac{9}{16}$	12	$1\frac{5}{8}$	5	$3\frac{1}{4}$	$3\frac{1}{4}$		

40. Square-Threaded Screws.—Plate VII., figs. 86, 87 represent a right-handed square-threaded screw $2\frac{1}{2}''$ diameter, and having two threads per inch, or $\frac{1}{2}''$ pitch. A section of the thread of the screw made by a plane passing through SP, fig. 86, is a square whose side $= \frac{1}{2}$ the pitch, the space being a square of equal side. The thread and space, therefore, make up the pitch; but this refers only to *single-threaded screws.* We shall refer to this point shortly. The curves for the elevation of the screw, fig. 87, are projected in a manner similar to that of the preceding examples, as shown by the construction lines; the only difference is in the form of the thread, there being two parallel curves for the top and two for the bottom of the thread in square-threaded screws. At *ef*, fig. 87, the back half of the thread is shown in dotted lines, portions of which, *fg*, *eh*, are in full where they cross the space. It will be noticed the dotted curves are inclined in the opposite direction to those shown in full.

41. As previously stated, Art. 28, page 37, the bearings of screws are *nuts* which fit the former accurately. Figs. 88, 89, represent in half-plan and sectional elevation a nut for the screw shown in figs. 86, 87. The curves are exactly similar to those of the screw, and in the half

shown in fig. 89, they are inclined in the same direction as the dotted curves *ef*, fig. 87; in the half of the nut removed they are in the opposite direction.

The construction lines show how fig. 89 is drawn. Fig. 90 is a section of the threads of the screw and nut, showing them in contact.

42. In figs. 83, 84, and 86, 87, we have shown how to draw the true form of the threads of screws, V and square-threaded; however, in most instances, approximations to the true form are employed, and, generally, the smaller the scale of the drawing the further the approximations are carried. Figs. 91, 92, Plate VIII., represent the V-threaded screw shown in figs. 83, 84, drawn to a scale of $\frac{1}{2}$; the curved lines *aa*, *a′a′* are here replaced by straight lines. Fig. 94 is drawn to a scale of $\frac{1}{4}$, the Vs not being shown. In smaller scale drawings lines are used to represent the tops of the threads only, as at *e*, *d*, fig. 70. Figs. 95, 96 represent a *right-handed double square-threaded screw*, $2\frac{1}{2}''$ diameter, $1''$ pitch, scale $\frac{1}{2}$. The curved lines are replaced by straight ones. As there are two independent threads on this screw, the sections of the thread and space will be squares whose sides $= \frac{1}{4}$ the pitch. If there were three threads on the screw, then the squares would have sides of $\frac{1}{6}$ the pitch.

43. We will now define the term *pitch*, so that it shall be independent of the number of threads in the screw, which we consider to be the clearest manner of expressing it. In all cases either the screw or the nut is fixed, and prevented from moving lengthwise (in direction of the axis of the screw); we shall consider the nut to be the moving piece, as being most suitable for the definition. The *pitch* of a *screw* is the distance moved through by the nut during one revolution of the screw. To find the size or thickness of the thread for square-threaded screws, divide the pitch by twice the number of threads in the screw, and the quotient will be the required size. In fig. 96, $ab =$ the pitch, and therefore the thickness of the thread $= \frac{1}{4}\, ab$.

44. Screws are right or left-handed, according to the direction in which the nut moves; when the screw is turned round in the direction of the hands of a watch, the nut moves in the direction *ba*, figs. 92, 94, 96, *from left to right*, the screw is therefore *right-handed;* and *left-handed* if *vice versâ*.

A left-handed square-threaded screw, $2\frac{1}{2}''$ diameter, $\frac{1}{2}''$ pitch, is shown in figs. 97, 98, drawn to a scale of $\frac{1}{4}$. Fig. 98 shows a common approximation to the true form of the thread. If the screw be turned round in the direction indicated by the arrows, the nut will move in the direction *ab*, *from right to left.*

Screws are considered to be right-handed single thread, unless otherwise stated. Left-handed screws are only used in special cases.

45. For square-threaded screws there is no strict standard for the number of threads per inch of length according to the diameter of the screw, as there is for the V-threaded screw. In some establishments the rule is, for the same diameter of screw, to allow the number of threads per inch to be one-half that of the V-threaded screw. This rule agrees very nearly with the following table :—

TABLE III.

Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.	Dia. of Screw.	No. of Threads per in.
$\frac{1}{4}$	10	$\frac{5}{8}$	7	1	5	$1\frac{3}{4}$	$2\frac{1}{2}$
$\frac{5}{16}$	10	$\frac{11}{16}$	7	$1\frac{1}{8}$	4	$1\frac{7}{8}$	$2\frac{1}{4}$
$\frac{3}{8}$	9	$\frac{3}{4}$	6	$1\frac{1}{4}$	$3\frac{1}{2}$	2	$2\frac{1}{4}$
$\frac{7}{16}$	8	$\frac{13}{16}$	6	$1\frac{3}{8}$	3	$2\frac{1}{8}$	$2\frac{1}{4}$
$\frac{1}{2}$	7	$\frac{7}{8}$	6	$1\frac{1}{2}$	3	$2\frac{1}{4}$	2
$\frac{9}{16}$	7	$\frac{15}{16}$	6	$1\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$	2

CHAPTER VII.

46.. In this chapter we shall consider some of the kinds of wheels used as connecting pieces between shafts for the direct transmission of motion.

Spur Wheels are used for the purpose of transmitting motion from one shaft to another when the shafts are parallel. If the wheels are circular the motion is regular; and it is irregular in the case of *elliptic* and *lobed* wheels. We shall only consider the former kind, and confine ourselves to the simplest form of spur wheels, those having teeth projecting from the rim and parallel to the axis of the wheel. By giving proper diameters to the wheels we may obtain any required number of revolutions, within certain limits, for each shaft respectively.

47. In figs. 99, 100, Plate IX., A and B are the centres of two shafts, which are required to be connected by spur wheels, so that B shall make two revolutions to one of A. Required the diameters of the wheels. From A draw any line A*b*, making an angle of about 30° with AB, and upon it set off A*c*, *cb*, so that A*c* = 2*cb*. Join B*b*, and from *c* draw *c*C, parallel to B*b*, cutting AB in C, then AC, BC are the required semi-diameters or radii. We could have found C by dividing AB by trial, as the division is a simple one; but the plan adopted can be applied whatever be the ratio of the diameters of the wheels, and is therefore a general solution. The wheel A we shall term the *driver* and B the *follower*.

The act of giving motion to a piece is termed *driving* it, and that of receiving motion from a piece is termed *following* it.*

In this example we have considered the wheels to be toothless, and to be *rolling* together without *sliding*, so that for each inch or fraction of an inch of the circumference of the wheel A passing the point C, an equal length of the circumference of the wheel B passes the same point. The two shafts rotate in opposite directions; thus, if A turns in the direction of the hands of a watch, B will turn in the opposite direction. Wheels used to transmit motion are usually provided with *teeth* to ensure regularity of motion and the transmission of greater force than could be obtained conveniently with toothless wheels. The circles CDE, CFH, then become the *pitch circles* of the wheels, which are situated near the middle of the length of the teeth. See Ch. IX. on the Teeth of Wheels.

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* *Principles of Mechanism*, by Prof. Willis.

48. The diameters of wheels are generally referred to their pitch circles; thus we speak of the diameter of the pitch circle of a wheel of, say, 30 *teeth*, 1″ *pitch*. Figs. 101, 102 represent a pair of wheels in *outline* (not showing the form of the teeth), A has 24, and B 18 teeth, $\frac{3}{4}''$ pitch. The *pitch* is the distance, measured along the pitch circle, from the centre of one tooth to the centre of the next tooth. In fig. 101 the dotted circle marked *t* represents the top, and that marked *b* the bottom of the teeth. A is a *plate* wheel, the *boss* is marked *a*; *c* is the plate, and *d* the *rim* of the wheel. The wheel B is solid, having projecting pieces, *e*, on each side, termed *facings*. The figures are drawn to a scale of $\frac{1}{4}$. To draw the wheels it is necessary to know the distance AB and the diameter of one of the wheels, from which we can readily obtain the diameter of the other, or the diameters of both wheels. We will take the problem as follows:—

49. Given the number of teeth and the pitch of a pair of spur wheels, and the kind of wheels (solid, plate, or with arms), to make a drawing of them in outline. Having drawn the common centre line AB, fix upon A or B for one centre; now find the diameter of each pitch circle, which may be done as follows:—The diameter of a circle bears a constant ratio to its circumference, the ratio is 1 : 3·1416, or 1 : $3\frac{1}{7}$ nearly, that is to say, the circumference is 3·1416 times the diameter; therefore, knowing the number of teeth and the pitch, we can easily find the

of the circumference of the wheel B passes the same point. The two shafts rotate in opposite directions; thus, if A turns in the direction of the hands of a watch, B will turn in the opposite direction. Wheels used to transmit motion are usually provided with *teeth* to ensure regularity of motion and the transmission of greater force than could be obtained conveniently with toothless wheels. The circles CDE, CFH, then become the *pitch circles* of the wheels, which are situated near the middle of the length of the teeth. See Ch. IX. on the Teeth of Wheels.

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Plate X.

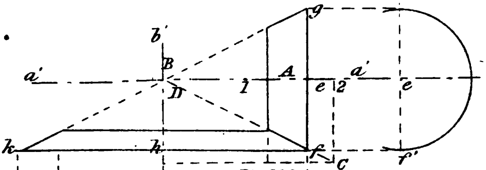


Fig. 103.

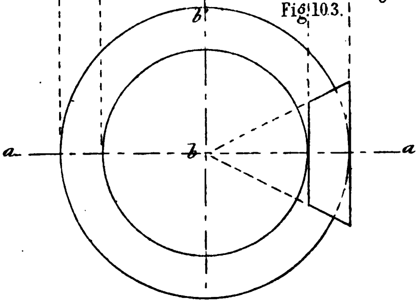


Fig. 104.

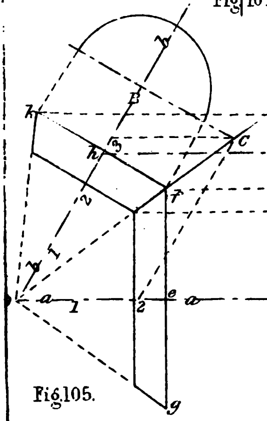


Fig. 105.

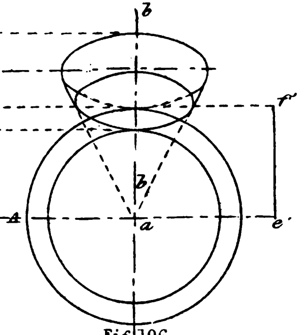


Fig. 106.

Plate XI.

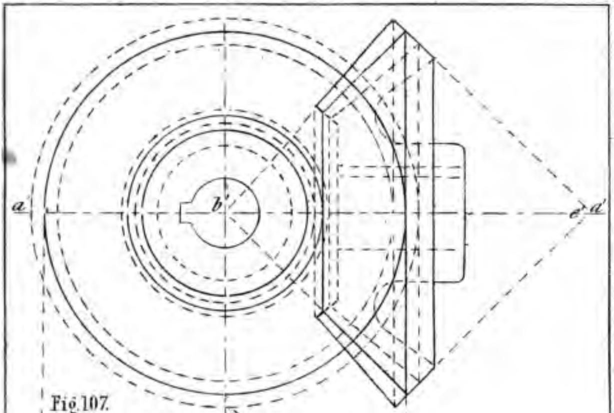


Fig. 107.

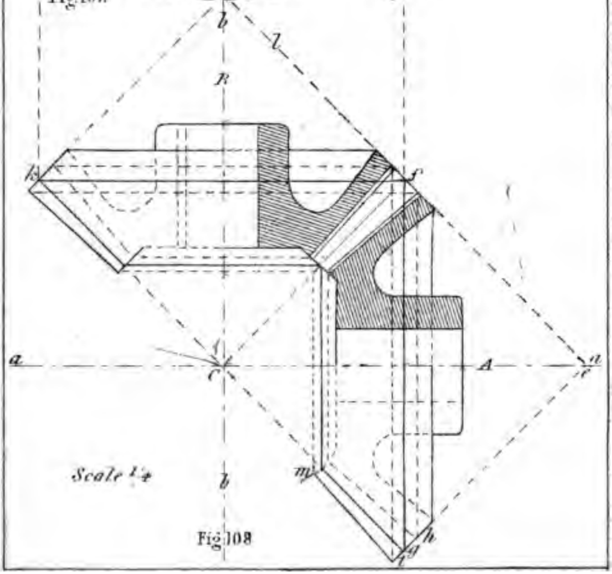


Fig. 108

then D*fk*, D*fg* are two cones which are the pitch surfaces of the required wheels, as in the last example; frusta of these cones are used for the wheels. The same equations are applicable for bevel wheels as those given for spur wheels in Art. 50, page 59.

53. We will now take an example, applying it to the case of equal bevel wheels with axes at right angles, called *mitre wheels.* Fig. 107 is an elevation, and fig. 108 a plan, of a pair of mitre wheels in *gear* of 24 teeth, 1″ pitch; the diameter of pitch circle = 7·636″, or $7\frac{5}{8}''$ nearly. Draw the centre lines *aa*, *a′a′*, *bb*, *b′b′*, and the pitch circles *kf*, *fg* in plan and elevation, join C*f*, C*g*, C*k*, fig. 108. From *f* draw *fe* perpendicular to C*f*, meeting the axis *aa* in *e*, and join *eg*; then *eg* is perpendicular to C*g*. Draw similar lines from *f* and *k* for the other wheel. From *f* along *lfe* set off the top *t* and bottom *p* of the teeth of each wheel, as shown at *g*; from each of these points draw lines to C. Upon *f*C or *g*C mark off *gm*, equal the width of the teeth, making both wheels similar. The construction lines show how to complete the drawing. The teeth of bevel wheels are made of the same size as the teeth of spur wheels of the same pitch at *tgp*, fig. 108, but as they radiate to a common centre C, they decrease in size the nearer they are to that centre. The following dimensions may be added:—Diameter of hole for shaft $1\frac{1}{2}''$; diameter of boss $2\frac{3}{4}''$; width through boss $2\frac{5}{8}''$; width of teeth *gm* $2\frac{1}{2}''$; and the key $\frac{5}{16}''$ square. The other proportions of the teeth are to be taken from one of the sets of dimensions given in Art. 66, page 71.

We shall treat bevel wheels more fully in the Advanced Work of this Series.

CHAPTER VIII.

54. THE connection between shafts by means of pulleys and bands for the transmission of motion.

Pulleys and Bands.—In the previous chapter we considered how motion could be transmitted by wheelwork; we shall now refer to a more simple and less expensive means of obtaining similar results; it is one, however, which can only be applied in cases where the motion transmitted may vary in extreme cases without causing serious inconvenience, as for instance, when one shaft turns round a fraction of a revolution more or less than the other. However, there are cases where pulleys and bands cannot be used for other reasons, but these refer more especially to the transmission of motion between shafts in machines where the space is limited, and where a direct connection is essential. The arrangement under consideration has many advantages over that of connection by wheelwork; one is that the shafts may be any distance apart within reasonable limits; and a second is, that any variation of the distance between the shafts does not alter their rate of motion, as the band can be adjusted to suit the change, and the pulleys can be made of a relative diameter, so as to produce the required number of revolutions per minute of each shaft independent of the distance between them. One important advantage of the pulley and band arrangement is, that if, through accident or otherwise, any sudden strain is thrown on, which might cause breakage in wheelwork, the band will *slip* on the pulley; by adjusting the band any required degree of tension may be obtained.

55. The band or other connecting piece between the pulleys is made of various materials and of two principal forms—flat and round. As the flat band (belt or strap) is the one chiefly used, we shall confine our examples to this form. The material commonly used is leather, as it possesses several important qualities suitable for the purpose; there are, however, several composite materials used for the purpose.

56. In figs. 109, 110, S_1, S_2 represent two parallel shafts, of which S_1 is the driver; they are to be connected by pulleys and belt, so that for every revolution of S_1, S_2 shall also make a revolution, and the direction in which they turn shall be the same, as shown by the arrows in fig. 109. The diameters of the pulleys on S_1 and S_2 will therefore be equal, as would be the case if they were toothed wheels. The amount of belt surface in contact with the pulley on S_1 is equal to *aa*, and that on S_2 to *bb*; and as the pulleys are of the same diameter *aa* = *bb*.

This is termed the *open belt* arrangement.

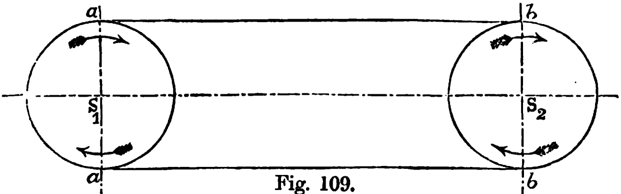


Fig. 109.

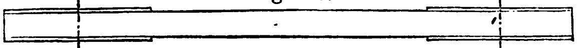


Fig. 110.

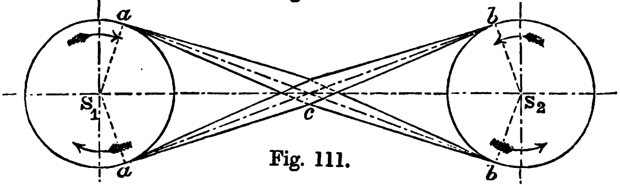


Fig. 111.

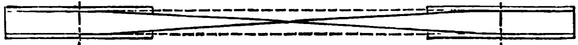


Fig. 112.

57. If the shafts are required to turn in opposite directions the belt is *crossed*, as shown in figs. 111, 112: not only is a difference produced in the direction of the motion of the shafts, but also a greater amount of belt surface is brought into contact with the pulleys than in the open belt, as shown at *aa*, *bb*, fig. 111. The belt, in passing from *a* to *b*, turns through two right angles; at *c*, where the two portions of the belt, *ab*, *ab*, cross, sidered how motion could be transmitted by wheelwork; we shall now refer to a more simple and less expensive means of obtaining similar results; it is one, however, which can only be applied in cases where the motion transmitted may vary in extreme cases without causing serious inconvenience, as for instance, when one shaft turns round a fraction of a revolution more or less than the other. However, there are cases where pulleys and bands cannot be used for other reasons, but these refer more especially to the transmission of motion between shafts in machines where the space is limited, and where a direct connection is essential. The arrangement under consideration has many advantages over that of connection by wheelwork; one is that the shafts may be any distance apart within reasonable limits; and a second is, that any variation of the distance between the shafts does not alter their rate of motion, as the band can be adjusted to suit the change, and the pulleys can be made of a relative diameter, so as to produce the required number of revolutions per minute of each shaft independent of the distance between them. One important advantage of the pulley and band arrangement is, that if, through accident or otherwise, any sudden strain is thrown on, which might cause breakage in wheelwork, the band will *slip* on the pulley; by adjusting the band any required degree of tension may be obtained.

55. The band or other connecting piece between the pulleys is made of various materials and of two principal forms—flat and round. As the flat band (belt or strap) is the one chiefly used, we shall confine our examples to this form. The material commonly used is leather, as it possesses several important qualities suitable for the purpose; there are, however, several composite materials used for the purpose.

56. In figs. 109, 110, S_1, S_2 represent two parallel shafts, of which S_1 is the driver; they are to be connected by pulleys and belt, so that for every revolution of S_1, S_2 shall also make a revolution, and the direction in which they turn shall be the same, as shown by the arrows in fig. 109. The diameters of the pulleys on S_1 and S_2 will therefore be equal, as would be the case if they were toothed wheels. The amount of belt surface in contact with the pulley on S_1 is equal to *aa*, and that on S_2 to *bb*; and as the pulleys are of the same diameter *aa* = *bb*.

This is termed the *open belt* arrangement.

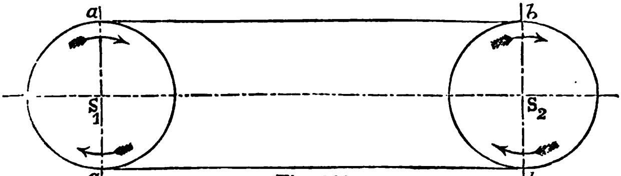


Fig. 109.

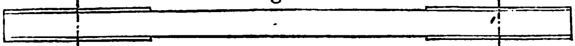


Fig. 110.

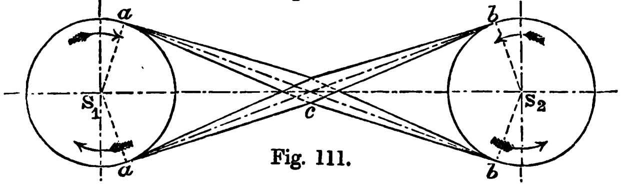


Fig. 111.

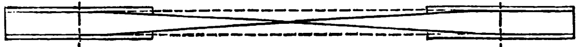


Fig. 112.

57. If the shafts are required to turn in opposite directions the belt is *crossed*, as shown in figs. 111, 112 : not only is a difference produced in the direction of the motion of the shafts, but also a greater amount of belt surface is brought into contact with the pulleys than in the open belt, as shown at *aa*, *bb*, fig. 111. The belt, in passing from *a* to *b*, turns through two right angles; at *c*, where the two portions of the belt, *ab*, *ab*, cross, they are at right angles to the position in whi leave the pulleys at *aa*, *bb*.

58. In the two examples shown in figs. 109- pulleys are of equal diameter, therefore the nu revolutions of each pair of shafts will be the san by varying the diameters of the pulleys in the sar ner as in a pair of toothed wheels, we can give a of number of revolutions to the two shafts within limits; for example, if the pulley on $S_1 = 24''$ di and that on $S_2 = 8''$ diameter, then S_2 will mak revolutions to one of S_1.

When a very great difference in the numbe volutions of tw is required, on or more inter shafts and pulle be employed.

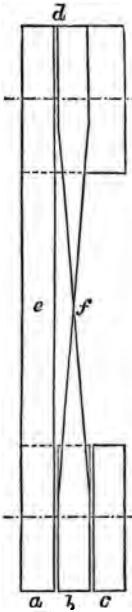


Fig. 113.

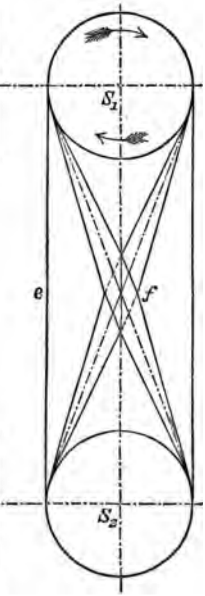
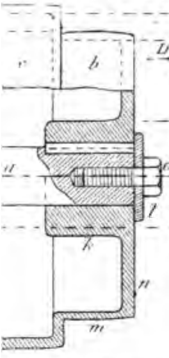


Fig. 114.

59. Pulleys a erally curved outer surface, a fig. 119, Plate which tends t the belt on the The greatest d of the pulley is middle of its b *pq*; and as th dency of the belt is to rise highest part pulley, the b thereby kept on the pulley convexity $= \frac{1}{2}''$ p of the breadth pulley.

60. The tv rangements shown in figs. 109-112 are often co



119.

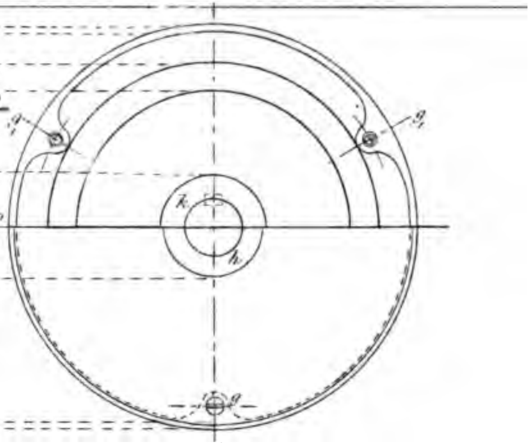
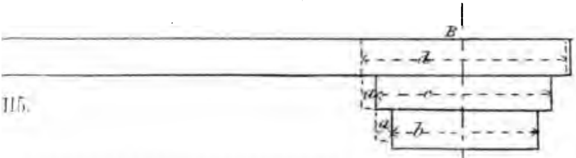
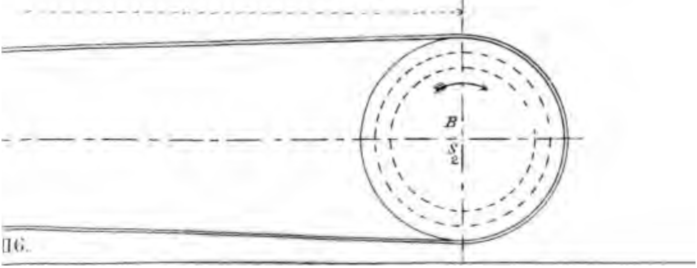


Fig. 118.



115.



116.

and employed as a reversing motion, which is illustrated in figs. 113, 114, where S_1, S_2 are two shafts, S_1 being the driver and S_2 the follower; *a*, *b*, *c* are three pulleys on the shaft S_2; *a* and *c* are keyed to the shaft, but *b* is loose upon it, so that it may turn without turning the shaft; *d* is a pulley keyed to the shaft S_1. Two belts are used, an *open* one *e* and a *crossed* one *f*, and they are so arranged that one of them is always upon the loose pulley. In the position shown in fig. 113 the open belt is on the fast pulley *a*, and the crossed one on the loose pulley *b*, so that S_2 turns in the same direction as S_1; if now the two belts are moved so that *e* is upon the pulley *b*, and *f* upon the pulley *c*, then S_2 will turn in the opposite direction to S_1. By this means a *reversing motion* is obtained for the shaft S_2. It is employed in planing machines, screw-cutting lathes, &c.

61. By using a fast and a loose pulley on the shaft S_2 and a single belt, the shaft may be stopped and started at pleasure; this is termed the *fast* and *loose* pulley arrangement.

62. **Cone or Speed Pulleys** are employed where a limited change in the rate of motion (number of revolutions per minute) of two shafts is required. Figs. 115, 116, Plate XII., represent an arrangement of speed pulleys; S_1 and S_2 are the two shafts, on each of which are fixed speed pulleys A and B respectively. Each pulley is made up of three pulleys or *speeds*, *b*, *c*, *d*, of different diameters, increasing in radii by a common quantity *a*. The pulleys are arranged as shown in the figures, so that the smallest speed of the set on A is connected with the largest of the set on B; and as the diameters *b*, *c*, *d* of the pulleys A and B are equal, the length of the belt is constant for each of the three positions in which it may be placed when connecting the speeds *b*—*d*, *c*—*c*, *d*—*b*. Let A be the driver, then when the belt is in the position shown (on *b*—*d*), S_1 rotates a greater number of times in a given time (a minute) than S_2; when the belt is on *c*—*c*, S_1 and S_2 rotate the same number

of times per minute; and when the belt is on d—b, S_1 rotates a less number of times per minute than S_2. By increasing the number of speeds a greater amount of variation can be obtained; however, it is not usual to employ more than six speeds.

63. The common quantity a is termed the *fall* or *step;* if the diameter of the smallest pulley $= b$, then the diameter of $c = b + 2a$, and the diameter of $d = c + 2a$; thus, let the diameter of $b = 12''$, and $a = 1\frac{1}{2}''$, then the diameter of $c = 12'' + 3'' = 15''$, and of $d = 15'' + 3'' = 18''$.

The *sums* of the diameters of the two connected pulleys are constant, thus $b + d = 12'' + 18'' = 30''$, $c + c = 15'' + 15'' = 30''$, and $d + b = 18'' + 12'' = 30''$. The arrangement is independent of the distance between the axes e. Speed pulleys are employed in a variety of machines, of which perhaps the most common is the lathe.

64. Figs. 117-119, Plate XII., are elevations of a speed pulley; the fall is $1\frac{1}{4}''$, and the diameters of the speeds are $1'..5''$, $1'..2\frac{1}{2}''$, and $1'..0''$. In this example the pulley is fixed on the end of a shaft a, one of the bearings of which is marked e, fig. 119. Fig. 117 is an end-elevation of fig. 119 projected in the direction D. Fig. 118 is an end-elevation of fig. 119 projected in the direction E; the top half of this figure shows the inside of the pulley, the plate f having been removed; the bottom half shows the plate in position. The greater portion of fig. 119 is in section, portion of the shaft is also in section showing the mode of connection between the pulley and shaft. The plate f is connected to the pulley by means of three screws g, one of which is shown in figs. 118, 119; in the top half of fig. 118 are shown the two holes g_1, to receive the screws g: this plate is provided with a boss h, which is *bored out* to the same diameter as the shaft upon which it runs loose. k is the boss of the pulley; the connection between the shaft and pulley is made by means of a key let into this boss and the shaft; l is a washer fixed to the shaft by means of a set-screw o, its use is to prevent the pulley from working loose on the shaft. The following are the remaining dimensions:—Width of each speed $3''$; boss k $4\frac{5}{8}''$ diameter × $3\frac{1}{2}''$ through; boss h $4''$ diameter × $3''$ through; diameter of the shaft a $2\frac{1}{2}''$; thickness of metal at f $\frac{7}{16}''$, at m $\frac{5}{16}''$, and at n $\frac{7}{16}''$; diameter of set-screw o $\frac{3}{4}''$; diameter of set-screws g $\frac{1}{2}''$; washer l $3\frac{1}{2}''$ diameter × $\frac{3}{8}''$ thick; key $\frac{1}{2}''$ square and $3\frac{1}{2}''$ long. The whole is of cast-iron except the shaft a, the screws g and o, and the washer l, which are of wrought-iron, and the key, which is of steel. The outer surface of the speeds is curved as shown at pq, the amount of convexity is that stated in Art. 59, page 66.

The drawing of these figures should present no difficulty to the student, as there are no lines to be drawn other than straight ones, circles, and arcs of circles; and they should be drawn to a scale of not less than $\frac{1}{4}$. *In all cases the student should work from the written dimensions when given,* rather than apply a scale to the figures, or copy off the dimensions by means of instruments. This remark applies to all the figures in this book, and generally in all cases.

CHAPTER IX.

65. On the Teeth of Wheels.—In chapter VII. we considered spur and bevel wheels, without respect to the form of the teeth; we shall now proceed to state the proportions of the teeth of such wheels, and certain practical methods of drawing them, leaving the consideration of the various curves used in their construction for our Advanced Work. In Art. 47, page 55, it is stated why teeth are necessary for wheels, and in Arts. 48 and 49, page 56, we worked out an example of a pair of spur wheels in outline; we will now complete the example for the wheel A showing the teeth.

66. Before working out this example, we will give the proportions of the several parts of the teeth. It is usual to refer the dimensions of the teeth to the pitch of the wheel. In fig. 120 is shown a tooth divided into its several parts; PC is the pitch line (a circle in the case of circular wheels), AD the pitch, T the top of the tooth (outside the pitch line), B its bottom (inside the pitch line), W the thickness, T + B the total depth of the tooth, and S the space between two consecutive teeth; AD, W, and S are measured along the pitch line; R is the thickness of the rim. One set of dimensions is shown in fig. 121, where *ab* represents the pitch ($1\frac{1}{4}''$ in the figure) and is divided into 10 equal parts; of these T = ·33, T + B = ·75, W = ·45, S = ·55, R = ·45; or, calling the pitch *p*, T = *p* × ·33, T + B = *p* × ·75, W = *p* × ·45, S = *p* × ·55, R = *p* × ·45. The usual width of the tooth on its face = *p* × 2·5.

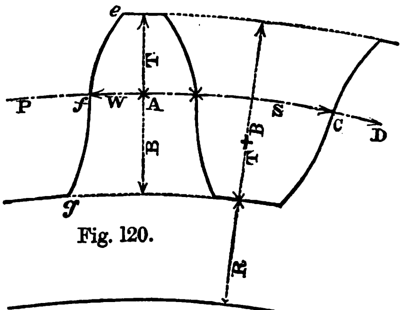


Fig. 120.

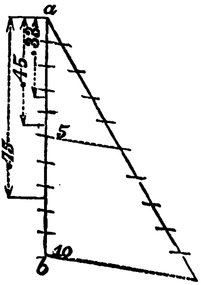


Fig. 121.

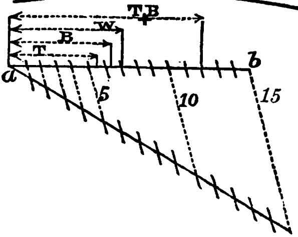


Fig. 122.

Plate XIII.

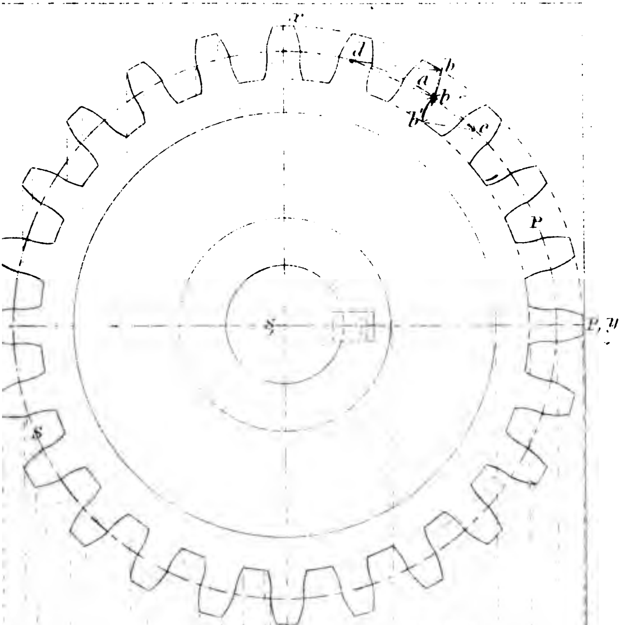
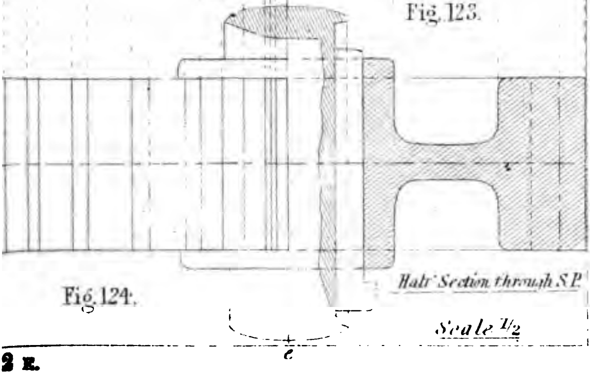


Fig. 123.



Half Section through S.P.

Scale 1/2

Fig. 124.

Another set of proportions is obtained by dividing the pitch into 15 equal parts, as shown in fig. 122, and making $T = \frac{5\frac{1}{2}}{15}$, $B = \frac{6\frac{1}{2}}{15}$, $W = \frac{7}{15}$, and $S = \frac{8}{15}$. There are other proportions used by different makers, which come very near to one or other of the above sets. The *form* of the tooth (*efg*, fig. 120) is of considerable importance; there are three chief forms in use; in the examples in this book we shall use the *cycloidal* form of tooth.

67. In figs. 123, 124, Plate XIII., is shown in elevation and plan the spur wheel of 24 teeth and $\frac{3}{4}''$ pitch, whose dimensions are given in Art. 49, page 56. We have substituted arcs of circles for the *epicycloids* and *hypocycloids* which form the curved surfaces of the teeth, as is usual in scale drawings; however, in making the wheels, the form of the teeth should be obtained correctly, and then approximations may be used for drawing purposes. The approximations employed in this example are very near the true form.

Having drawn the centre lines *ex*, *fy*, the pitch circle SP, and the circles for the top and the bottom of the teeth, divide the pitch circle into 24 equal parts; take one of the pitch points, as *a*, and mark on each side of it a distance $ab = \frac{1}{2}W$; from *d* as a centre with a radius *db* ($=$ the pitch $+ \frac{1}{2}W$) describe the top of the tooth *bb*; and from *c* as a centre with a radius *cb* ($=$ the pitch $- \frac{1}{2}W$) describe the bottom of the tooth *bb′* (the points *d* and *c* are the centres of the teeth on each side of *a*). Then *bbb′* is one side of a tooth; by repeating the operation its other side can be drawn, and in like manner the remaining teeth of the wheel. The student will find it better first to draw all the tops and then the bottoms of the teeth, so that only one alteration of his drawing instrument will be necessary. Fig. 123 is an elevation, and fig. 124 is a plan, of the wheel; the right-hand half of the plan is in section, as made by a plane S_1P_1, fig. 123, showing the key in position; the other half of the plan is an ordinary projection showing the teeth; the construction lines indicate how each is obtained. The top of the tooth is sometimes termed the *face*, and sometimes the *addendum*, while the bottom of the tooth is called the *flank*.

68. To facilitate the drawing of the teeth of wheels formed by cycloidal curves, an instrument has been designed by Professor Willis, by which arcs of circles are substituted for the curves; the result gives a very near approximation to the true form. The instrument is called by its inventor the *Odontograph;* fig. 125, Plate XIV., is a drawing of it to a scale of $\frac{1}{2}$. For practical use it may be cut out in card-board or sheet metal; the student will be able to construct the instrument from the figure and the following description:—Having provided a rectangular piece of card-board, $13'' \times 7\frac{1}{2}''$, upon one of its edges, as AB, take a point T about $2\frac{1}{2}''$ from B; on each side of T set off distances of $\frac{1}{2}''$; divide each of these into 10 equal parts, and number them as shown; from T draw TC so that the angle BTC contains 75°. The tables are to be copied from the figure; the top one contains the centres for the flanks, and the bottom one those for the faces of the teeth; the first column in each table contains a list of certain wheels of from 13 to 150 teeth; the whole of the wheels are not given, because the error in taking from the column the numbers for the wheel nearest to the one required is very small* and practically inappreciable. The remaining columns contain respectively the numbers for the centres of the faces and for the flanks of the teeth of the wheels given in the first column, for pitches advancing by quarter inches from $1''$ to $2\frac{1}{2}''$, and for a pitch of $3''$. The numbers for intermediate pitches may be found by direct proportion from those given; thus, for $\frac{1}{2}''$ pitch, by halving those of $1''$ pitch; for $3\frac{1}{2}''$ pitch, by doubling those of $1\frac{3}{4}''$ pitch; and so on for other pitches.

69. An example will explain how to use the instrument. In figs. 126 and 127, Plate XV., A is the centre

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* The error in the curves for a wheel of $3''$ pitch is less than $\frac{1}{300}$ of an inch.

Plate XIV.

THE ODONTOGRAPH

TABLES SHOWING THE PLACE OF THE CENTRES UPON THE SCALES.

CENTRES FOR THE FLANKS OF TEETH.

Number of Teeth.	Pitch in Inches							
	1	1¼	1½	1¾	2	2¼	2½	3
13	129	160	193	225	257	289	321	386
14	69	87	104	121	139	156	173	208
15	49	62	74	86	99	111	123	148
16	40	50	59	69	79	89	99	191
17	34	42	50	59	67	75	84	101
18	30	37	45	52	59	67	74	89
20	25	31	37	43	49	56	62	74
22	22	27	33	39	43	49	54	65
24	20	25	30	35	40	45	49	59
26	78	22	27	32	37	41	46	55
30	17	21	25	29	33	37	41	49
40	75	18	21	26	28	32	35	42
60	73	15	19	22	25	28	31	37
80	12	...	17	20	23	26	29	35
100	11	14	..	...	22	25	28	34
150	...	13	16	19	21	24	27	32
Rack	10	12	15	17	20	22	25	30

CENTRES FOR THE FACES OF TEETH.

12	5	6	7	9	10	11	12	15
15	..	7	8	10	11	12	14	17
20	6	8	9	11	12	14	15	18
30	7	9	10	12	14	16	18	21
40	8	..	11	13	15	17	19	23
60	.	10	12	14	16	18	20	25
80	9	11	13	15	17	19	21	26
100	..	..	.	..	18	20	22	...
150	...	..	14	16	19	21	23	27
Rack	10	12	15	17	20	22	25	30

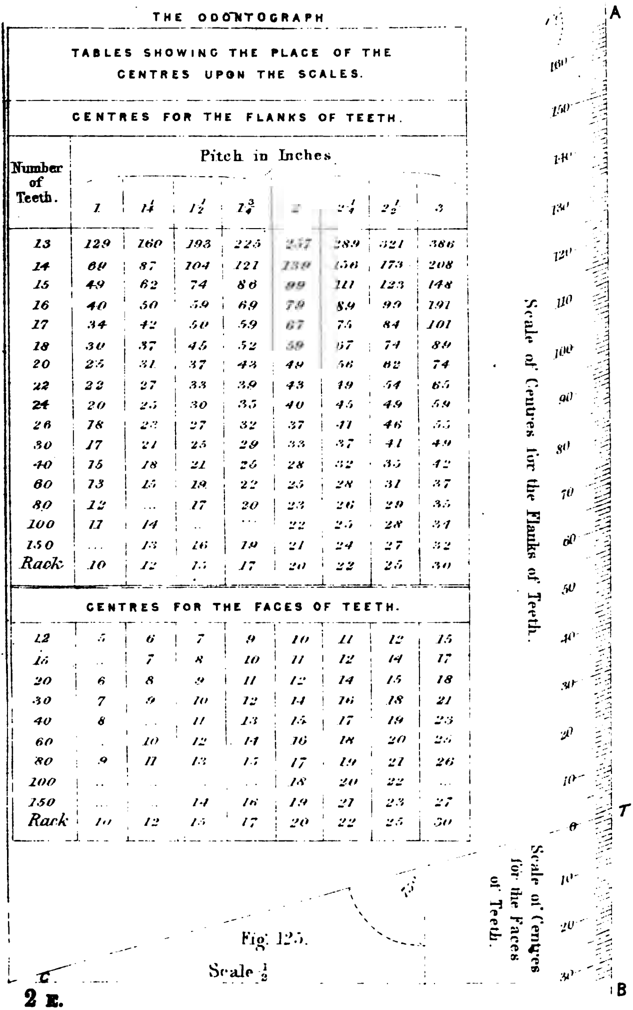
A
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
T
B
C
75°
Scale of Centres for the Flanks of Teeth.
Scale of Centres for the Faces of Teeth.

Fig: 125.

Scale ½

Plate XV.

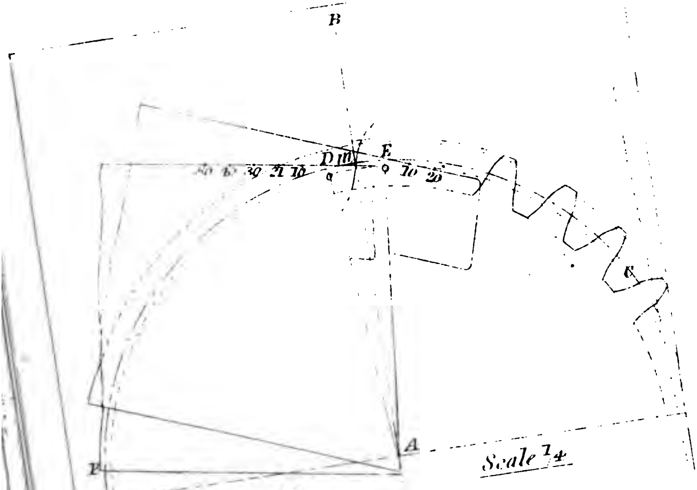

Fig. 126.

Scale ¼

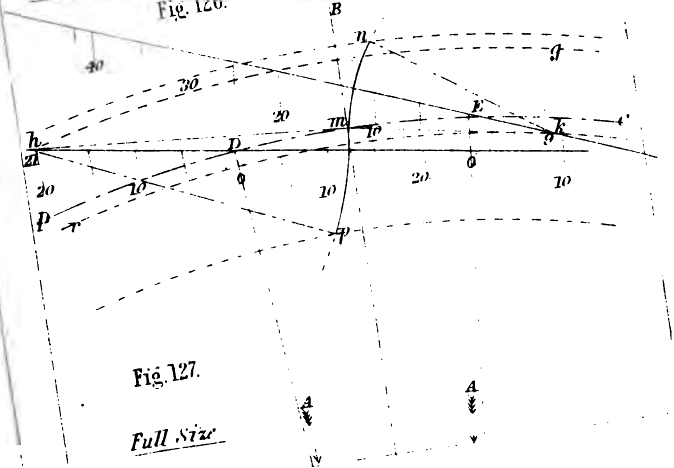

Fig. 127.

Full Size

and PC the pitch circle of a wheel of 29 teeth, $1\frac{1}{4}''$ pitch. Fig. 126 is drawn to a scale of $\frac{1}{4}$, and fig. 127 shows a portion of the former figure drawn full size. Let it be required to describe the teeth of the wheel. From A draw any radial line AB cutting the pitch circle in *m*, from *m* set off along the pitch circle *m*D, *m*E, each equal to one half of the pitch; from D, E, draw radial lines DA, EA. For the flank of the tooth place the line CT of the instrument upon the line AD, so that T coincides with D; now look to the table of *centres for the flanks of teeth*, and in the column of $1\frac{1}{4}''$ pitch, opposite 30 teeth (nearest to 29) is the number 21. The point numbered 21, counting from T to A, on the *scale of centres for the flanks of teeth* is the centre required; we will call the point *h*; and from *h* as a centre with a radius *hm* describe the arc *mp*, which is the required flank. To describe the face place the line CT upon AE; in the table of *centres for the faces of teeth* opposite 30 will be found the number 9, counting from T to B; mark off this number from the *scale of centres for the faces of teeth;* we will call the point *k*; from this point as a centre with a radius *km* describe the arc *mn*, which is the required face. By repeating these curves the other side of the tooth can be drawn, and also the remaining teeth. From A as a centre with radius A*h*, A*k*, respectively, describe circles *hq*, *rk*. These circles contain the centres (*h*, *k*) of all the teeth, which are to be described with the radii *hm*, *km*. We will apply the instrument to draw the teeth of a rack and pinion.

70. Rack and Pinion.—Figs. 128, 129, Plate XVI., represent, in elevation and plan, a rack and pinion in gear; the pinion A has 16 teeth, 1″ pitch; B is the rack, the pitch line of which is a tangent to the pitch circle of the pinion at the point *b*. Having drawn the centre lines, describe the pitch circle PC of the pinion, which is 5·091″ or $5\frac{3}{32}''$ diameter, and draw *pl* the pitch line of the rack; divide the circumference of the pitch circle into 16 equal parts, mark off the thickness of each tooth on the pitch circle, one half on each side of the points *s*, *t*, *u*, &c., then mark off the top and the bottom of the teeth from the first list of proportions given in Art. 66, page 71, and describe circles for them, as shown in the top left-hand quadrant of fig. 128. Now divide the pitch line of the rack for the teeth, so that a tooth of the rack shall be in contact with a tooth of the pinion, as at *a*, the pinion being the driver and turning in the direction indicated by the arrow.

To describe the teeth for the pinion, find the points *h* and *k* for the flanks and the faces of the teeth, as in Art. 69, page 76, the numbers being 40 and 6; through *h* and *k* describe circles having P for centre. These circles will contain the centres *h* and *k* for all the teeth; with *hm* and *km* as radii, describe the flanks and the faces of the teeth. In fig. 129 one half of the pinion is in section, as made by a section plane S_1P_1, fig. 128; the other half shows a projection of the teeth. The teeth of the rack are obtained in a manner similar to those of the pinion, as is shown in fig. 130, where *pl* is the pitch line, and where D, *m′*, and E, are points corresponding to D, *m*, and E, in fig. 127; AD and AE are drawn perpendicularly to the pitch line, because *pl* is a straight line. The points *h′*, *k′*, are obtained from the scales in the same way as for the pinion; the numbers 10 for the flanks and the faces are taken from the bottom line of the tables.

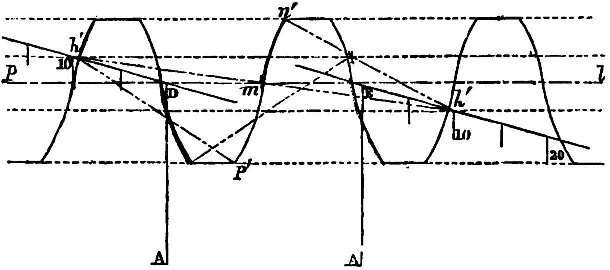

Fig. 130.

The teeth of the rack in fig. 128 are described in the same manner as those in fig. 130.

71. A Spur Wheel and Pinion in gear is shown in figs. 131, 132, Plate XVII. The pinion A is the driver, and the wheel B the follower; the former turns in the direction indicated by the arrow; the latter will therefore turn in the opposite direction. The teeth are of the same form as those previously described in Art. 69, and the pitch is $1\frac{1}{4}''$; A has 19 teeth, and B has 50 teeth. The diameters of the pitch circles are by equation (3), Art. 50, page 59, for A 7·558″ or $7\frac{9}{16}''$, and for B 19·890″ or $19\frac{7}{8}''$.

Having drawn the centre line *ay*, fix upon a point for the centre of one of the wheels, say, E for the pinion A; from E mark off along *ya* $Eb = \frac{1}{2}$ of $7\frac{9}{16}''$, and from *b* mark off $bD = \frac{1}{2}$ of $19\frac{7}{8}''$; through E and D draw the centre lines *dx*, *ez*. From E and D as centres with radius E*b* and D*b* respectively, describe the pitch circles PC, and circles for the top and the bottom of the teeth, taking the proportions for these and also those for W and R from fig. 121, page 72, and the list given in Art. 72. The teeth are to be described as shown in Art. 69; the centres *h* and *k* are taken from the tables of $1\frac{1}{4}''$ pitch, Plate XIV. The numbers for the faces are for A, 8, and for B, 10; which are the numbers for wheels nearest to the required ones. Those for the flanks are taken between 37 and 31 for A, and between 18 and 15 for B, which are the numbers for wheels of 18 and 20 teeth, and 40 and 60 teeth respectively.*

The pinion is solid, with facings on each side 4″ diameter, and $\frac{3}{16}''$ thick; the hole is 2″ diameter, and $3\frac{1}{2}''$ through; the key is $\frac{7}{16}''$ square. The wheel has six arms of a cross-section shown at X, fig. 131, as made by the plane S_1P_1; they are connected to the rim R and the boss K by feathers F, F; on both sides of each arm are feathers H, which also join the rim and the boss, the whole being cast together. The boss is 5″ diameter, and 4″

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* See foot-note to Art. 68, page 76.

through; the hole is $2\frac{1}{2}''$ diameter, and the key is $\frac{1}{2}''$ square.

72. The proportions of the several parts are as follow:—

The pitch . . . (=1·25″) $=p$.
Top of the tooth T . . . . . $=p\times$ ·33.
Bottom of the tooth B . . . $=p\times$ ·42.
Total depth of tooth T+B . . . $=p\times$ ·75.
Thickness of tooth on pitch line W . $=p\times$ ·45.
Space between teeth on pitch line S . $=p\times$ ·55.
Thickness of rim R . . . . $=p\times$ ·45.
Thickness of arms G . . . . $=p\times$ ·45.
Width of feathers F, F . . . $=p\times$ ·45.
Thickness of feathers H, F . . . $=p\times$ ·45.
Thickness of boss round shaft K . . $=p\times 1$.
Usual width of teeth L . . . $=p\times 2{\cdot}5$.

CHAPTER X.

73. The change of rotary or circular motion into reciprocating rectilinear motion by means of the Crank, the Eccentric, and Cams.

The Crank.—In this chapter we shall consider the change of motion as stated above, taking for the first example the crank and connecting-rod, which is the most common arrangement used. The crank consists of an arm AC, fig. 133, Plate XVIII., which turns about a fixed centre C; the end A therefore describes a circle at each revolution of the arm. Attached to A is one end A of a connecting-rod A*a*, while its other end *a* moves in the straight line *ba*CD. In this example we shall consider the crank to be the driver, because then the change is from circular to rectilinear motion; and we shall suppose it to be turning in the direction indicated by the arrow. For every revolution of the crank-arm AC, the end *a* of the connecting-rod moves through the space *bd* + *db*; or, in other words, if the crank starts from the initial position CD and moves in the direction DAB, and

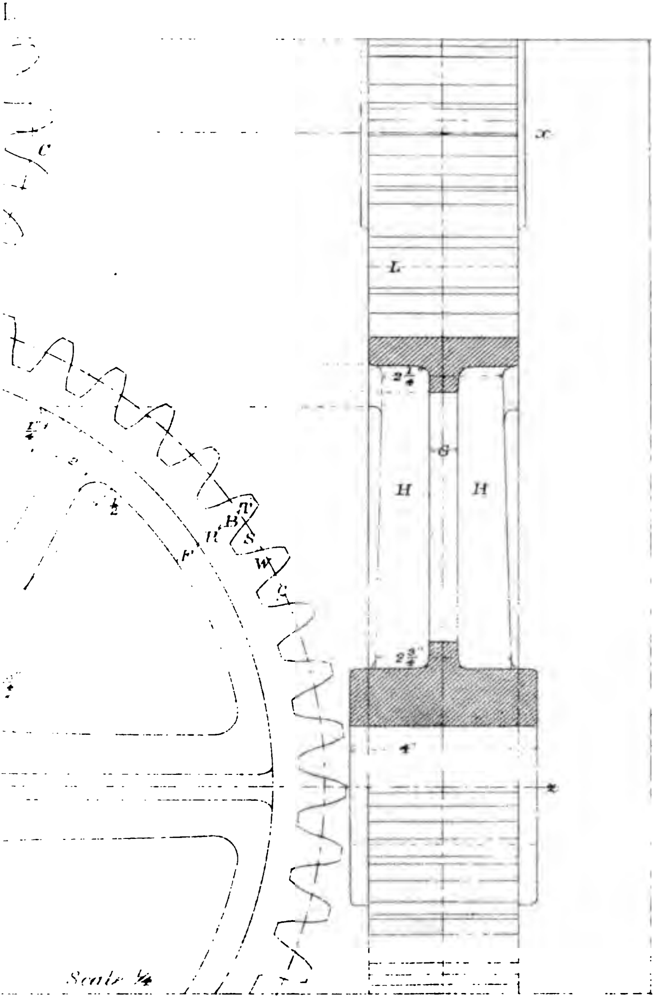


Fig. 132.

a starts from *d* moving in the direction *db*, at the same instant that A arrives at B, *a* will arrive at *b*; for the other half revolution B3D of AC, *a* will move from *b* to *d*. The distance *bd* (= BD) is termed the *stroke* of the crank, and is equal to 2AC. A being the centre of the *crank-pin*, the circle DAB is called the *path* of the crank-pin; the length of the path of the crank-pin is nearly 3·1416 times the length of the stroke.

74. Owing to the obliquity of the crank AC, which varies for every new position on each side of BD, except the positions BC, DC, the end *a* of the connecting-rod *a*A does not pass through equal spaces for equal arcs described by the crank. A common problem is to find the position of *a* for any given position of A, and *vice versâ*. By taking a number of positions for A we can find corresponding positions for *a*, and thus show the varying motion of *a* resulting from the regular motion of A. Divide the circumference of the semicircle B3D, fig. 133, into any convenient number of equal parts, say six; and from 1, 2, 3, &c., as centres with a radius equal to the length of the connecting-rod A*a*, describe arcs of circles cutting *bd* in 1, 2, 3, &c.; then the distances between *b*—1, 1—2, 2—3, 3—4, 4—5, 5—*d*, represent the spaces moved through by the end *a* of the connecting-rod for the equal arcs B—1, 1—2, 2—3, 3—4, 4—5, 5—D, described by the crank. The motion of *a* when it is in the position *b* is 0; in passing from *b* to 3 it increases from 0 to its maximum; and from 3 to *d* it decreases to 0; the point *c* marks the middle position of the path of the sliding end *a*. This variable motion of *a*, especially its decreasing at each end of the path, is of great advantage in some kinds of machinery.

75. In the steam-engine the reverse of the motion just described takes place; the sliding piece *a*, connected to the piston-rod of the engine, becomes the driver; the change is therefore from rectilinear to rotary motion.

76. In figs. 134, 135, Plate XVIII., is shown in plan and elevation one form of wrought-iron crank and crank-

shaft, the whole being welded together. AC is the crank arm, A the centre of the crank-pin B, C the centre of the crank-shaft, and D, D, are its bearings. The following are the dimensions:—AC (½ the stroke) is 7″; the diameter of the crank-shaft is 4″, the bearings are 6″ long and 3½″ diameter; the crank-arms are 4″ wide at *e*, and 2½″ thick at *f*; the distance *g* between the arms is 4¼″.

77. The drawing of these figures requires no special notice except for the curves *ab*, fig. 134, which we will now explain. Figs. 136, 137, represent a portion of the former figures, containing the curve *ab* drawn full size, and the mode of obtaining the plan of the curves. If the crank-arms, which are of a rectangular cross-section, were connected to the shaft, leaving angles at E, as AEB, fig. 137, the curved line *ab* would be a straight one *eb*; but for the purpose of strengthening such connections, angles are always avoided when circumstances permit; the angles AEB are *filled-up* leaving the outline, as seen at A, 1, 2, &c., to B, a quadrant of a circle, which is a projection of A′B′, fig. 136. This circular filling-up is continued on each side of A′B′, as shown at A′*a*′, B′*b*′. If we take sections as *kl*, *a*′*p*′, which do not pass through the centre of the shaft C, the plans of *mn*, *a*′*b*′ will not be circular as AB. The general problem will be to find the form of the curve made by such cutting planes. In the present case the cutting plane is represented by the surface *a*′*b*′*p*′, the cut portion of the circular filling-up being *a*′*b*′, of which we are required to show the plan. Divide AB into any number of parts, 1, 2, 3, &c., not necessarily equal parts; and through these points draw lines parallel to AA′ cutting A′B′ in 1, 2, 3, &c.; from C as a centre with radii C1, C2, C3, &c., describe arcs of circles cutting *a*′*b*′ in 1′, 2′, 3′, &c. From these points draw lines parallel to AA′ cutting lines drawn parallel to A*a* from 1, 2, 3, &c., fig. 137; and number the intersections of these lines I, II, III, &c. Through I, II, III, &c., draw the line *ab*, which is the required projection of *a*′*b*′.

78. We have employed the construction just described

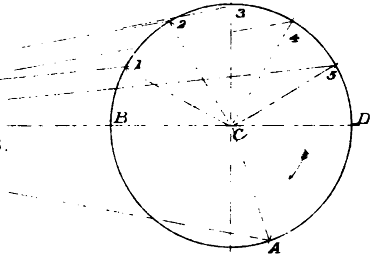
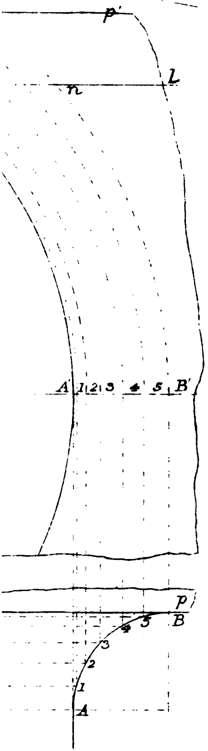


Fig. 133.



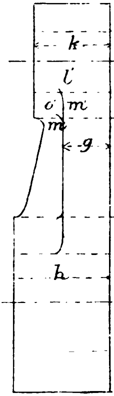


Fig 139

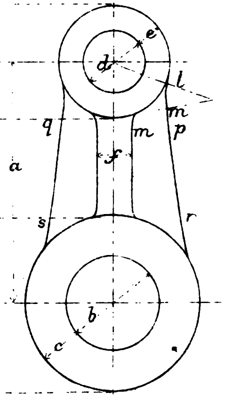


Fig. 138.

Scale 1/24

to find the form of the line joining *ab*; to do this we have divided the portion of the solid between A*a*, B*b*, by a number of vertical planes, which are represented by *q*1, *r*2, *s*3, &c., in fig. 137, and by 11′, 22′, 33′, &c., in fig. 136; the projections of the intersections of these planes with *a′b′* are the points 1′, 2′, 3′, &c., in fig. 137, and I, II, III, &c., in fig. 136, which when joined are the required line. The number of sections to be taken depends upon the degree of accuracy with which the curve is to be delineated. In scale drawings it is not usual to make constructions for such curves as the one described; the draughtsman, by frequent application, knows the form, and makes use of an approximation, which is a good one or otherwise according to his ability to describe the curve accurately.

79. A common form of cast-iron crank is shown in figs. 138, 139, drawn to a scale of $\frac{1}{24}$, the drawing of which should present no difficulty after working out the previous examples; however, as the curves *l′m′*, *m′o′*, are the projections of the intersections of two curved surfaces, and therefore somewhat different to the preceding example, we have worked them out in figs. 140, 141, Plate XIX., for the small end of the crank; those for the large end are obtained in a similar manner. The angle formed by the connection between the *web g* and the *boss e* is filled-up by a quadrant-shaped surface *mn*, *m′n′*; the circular surface *ml* cuts this surface; the curve *m′l′* is therefore the projection of the intersection of the two curved surfaces *ml*, *mn*; and similarly the curve *m′o′* is the projection of the intersection of *mo*, *mn*, which connects the *web g* and the *feather f* with the boss. The web and the feather are also connected by a curved surface similar to *mn*, *m′n′*. The construction lines show how the curves *l′m′*, *m′o′*, are obtained; the method used is the same as that employed for the preceding figures, *lm* in fig. 140 corresponding to *a′b′* in fig. 136; the only difference is that *lm* is a curved surface, whereas *a′b′* is a plane surface.

80. The dimensions of the crank are as follow (see figs. 138, 139):—$a = 2'..6''$, $b = 12''$, $c = 5''$, $d = 7\frac{1}{2}''$, $e = 3\frac{1}{4}''$, $f = 4''$, $g = 6''$, $h = 12''$, $k = 9\frac{1}{2}''$, $pq = 1'..1''$, $rs = 1'..4\frac{1}{2}''$; where a stands for half the stroke, b the diameter of the crank-shaft, c the thickness of metal round the shaft, d the diameter of the crank-pin in the crank, e the thickness of metal round the pin, f the thickness of the feather, g the thickness of the web, pq and rs the width of the web at pq and rs respectively, h the depth at the shaft end, and k the depth at the pin end.

81. **The Eccentric** is employed to change rotary into reciprocating rectilinear motion, chiefly where the extent of the motion is small compared with that obtained from the crank; one special feature in the eccentric arrangement is, that it can be applied to shafts without necessarily being fixed at one end, or causing a break in the length of the shaft, as at *v*, *w*, fig. 134. In figs. 143 to 145, Plate XX., is shown an eccentric which consists of a circular plate A, termed the *sheave*, usually keyed to the shaft S. The centre of the sheave and that of the shaft are a certain distance BC apart, this is termed the *eccentricity;* twice the eccentricity BC (= BD) is termed the *throw*, and corresponds to the *stroke* of the crank. As the sheave is fixed to the shaft it turns with it; the motion is taken from the sheave by means of the *strap* E, which consists of a ring in halves fitting into a groove cut in the sheave, and connected by bolts F, F. The strap does not turn round with the sheave, but oscillates, having P for a centre; and at the same time it receives a motion in directions BD, DB; therefore the strap must not fit the sheave too tightly. At G are inserted pieces of metal or hard wood, by adjusting the thickness of which, compensation can be made for the wear between the surfaces of the sheave and the strap. Attached to the strap by means of bolts, or by a *cotter*, as in the figures, is a rod HK which transmits the motion to the piece to be operated upon, as the slide-valve of a steam-engine, as in the the example, where L is one end of the valve-rod.

82. The dimensions of the several parts of the figures

shown in Plates XX. and XXI. are as follow:—The throw BD is 2½″, the diameter of the shaft S is 3½″, the key T is ¾″ × $\frac{7}{16}$″, and it is let into the shaft ⅛″. The sheave A is 7¾″ diameter outside, 7¼″ diameter at the bottom of the groove, and 2″ wide; the width of the groove is 1½″; the thickness of metal round the shaft is $\frac{13}{16}$″, at *g* it is 1″ thick to allow for the key-way; the rim *e* is ½″ thick, and the arm *f* is ¾″ wide. The strap E is 7¼″ diameter inside, and 8¼″ diameter outside; the width is 1½″ *bare;** each half is provided with *lugs* ⅝″ thick, through which pass bolts F ¾″ diameter; the distance, centre to centre, of the bolts is 9½″; at V on one half of the strap is a boss 1½″ diameter to receive one end of the rod HK; U, U, are feathers ½″ wide, whose object is to strengthen the connection between the boss and the strap; W is a collar on the boss V 1⅝″ diameter and ⅜″ wide; the distance from the outside of the collar to the centre B of the strap is 6″. The cotter Q is 3″ long, $\frac{3}{16}$″ thick, and ⅞″ wide in the middle; the amount of *taper* in its length is ½″ per foot; M is an oil-cup forming part of the strap, a section of which is given in fig. 146; R is a hole through which the oil passes; the cup is 1½″ diameter outside, and 1¼″ diameter inside; the tube is ½″ diameter, the hole ¼″ diameter; the distance from the top of the cup to the centre line is 4⅛″; the cup is provided with a cover O, which is screwed into the cup; the diameter of the screwed part is 1″, but the thread is finer than that given for 1″ diameter in Table II., page 48. The edge of the cup-cover is generally *milled,* to allow of a better hold being taken when unscrewing it. The other dimensions may be taken from the figures. The eccentric-rod HK, is 2′.. 5½″ from the centre P to the outside of the collar; the portion in the boss V is 1⅞″ long and ⅞″ diameter; the rod is ⅞″ diameter at each end, and increases to 1⅛″ in

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* To allow the surfaces of the strap and the sheave to slide past each other, one of them must be made a little less than the other, the term *bare* is used to denote this difference, which cannot be shown in the drawing.

the middle; the end K of the rod is *forked*, and through it passes a pin X, connecting the valve-rod L to it; between the fork and the cylindrical portion K the cross-sections are rectangular and square; a portion of the latter has its edges chamfered, leaving the section an octagon, as shown in fig. 155. The dimensions of the forked end are marked on the drawings, figs. 153, 154. The pin X is prevented from leaving its position by means of a pin Y which passes through the former; between the pin and the fork is a washer 1″ diameter and $\frac{1}{8}$″ thick; the pin Y may be either a piece of round *wire*, or of the form shown in fig. 156, which is termed a *split-pin;* the cross-section of the wire out of which it is made is a segment of a circle, nearly a semicircle; by opening out the halves of the pin at *a*, it is prevented from leaving the hole in which it is placed. The sheave is cast-iron, the strap is brass, and the rod, pin, washer, and cotter, are wrought-iron.

83. Fig. 142, Plate XX., represents in outline the eccentric arrangement; the centre line $a'y'$ is the path of the valve-rod, which passes through the centre C of the shaft; BEDF is the path of the centre of the eccentric; BD is the throw; the positions b, d, of the rod end correspond to the positions B, D, of the eccentric; $bd = \text{BD}$. The sheave is shown in four positions, I, II, III, IV, whose centres are B, E, D, F, respectively; the variable motion obtained from this arrangement is similar to that obtained from the crank as shown in fig. 133, Plate XVIII.

84. The general problem is, given the throw of the eccentric and the diameter of the shaft upon which it is to be fixed, to make a drawing of the arrangement. In Plate XX., figs. 143 to 145, we have worked out the example, of which the dimensions are given in Art. 82, page 94. Fig. 143 is a front-elevation, fig. 144 is a plan, and fig. 145 is an end-elevation; they are drawn to a scale of $\frac{1}{4}$. Fig. 146 shows a portion of the sheave and the strap with the oil-cup in section; fig. 147 is a plan of

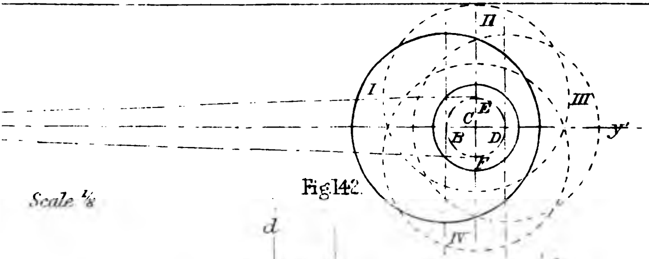
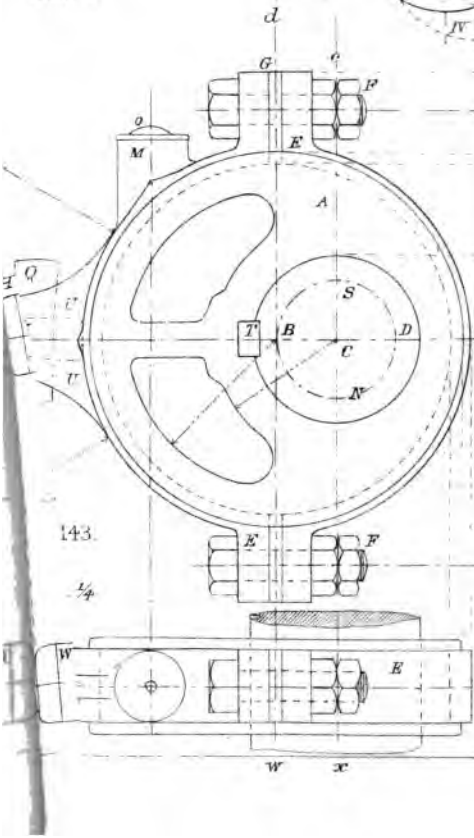


Fig 142.

Scale 1/8



143.

1/4

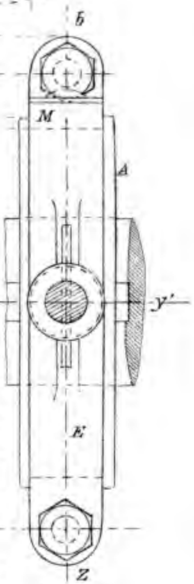


Fig 145.

the same; scale for both $\frac{1}{2}$. Figs. 148 to 156, Plate XXI., are portions of the figures shown in Plate XX. drawn to a scale of $\frac{1}{2}$.

85. The drawing of the figures in Plates XX. and XXI. is as follows:—Draw the centre lines *ay*, *a′y′*, *bz*, *cx*; let C be the centre of the shaft; from C as a centre with a radius CB (one-half the throw), describe a circle BDN, which is the path of the centre of the sheave; through B draw the line *dw*, this will be the centre line of the sheave and the strap. From C and B as centres describe the circles for the shaft, &c.; and from the dimensions given, and from the construction lines shown, proceed to draw the figures. The only special points to be noticed are the intersections of the oil-cup with the strap, of the feathers U with the boss V and with the strap, and of the boss with the strap. These points we will now refer to.

The intersection of the oil-cup with the strap would be a case of the intersection of two cylinders whose axes are at right angles, but not in the same plane, as shown in figs. 143, 146, and 148; but the angle formed by the two cylindrical surfaces, as seen in those figures, is filled-up with a curved surface, and therefore there is no line of intersection to be seen in fig. 150. If the filling-up were omitted, the dotted line 0′ 1′ 2′ 3′, fig. 150, would represent a portion of the intersection of the two cylinders. On the right of fig. 150 is shown, by a dotted line 0 to 6, one-half of the *junction* of the curved surface, at the bottom of the oil-cup, with the strap; but there is no line produced, as it is not an *intersection*, because the two surfaces blend into one. However, we require the line to find the intersection of the curved surface with the face of the strap, as shown at 2*h*′4, fig. 148; the outer circle of the strap does not pass over the surface of the cup between 2 and 4, fig. 148, but terminates at these points, and then takes the curved form as shown. The boss V is joined to the strap by a surface similar to the one just described; the feathers U, U, are also connected to the boss and the strap by curved surfaces, and therefore, for the same reason as before, there is no line to be seen; the dotted line on the boss in fig. 148 represents the junction of the two surfaces.

86. We have shown in Plate XXII., figs. 157 to 160, the oil-cup and a portion of the strap drawn full size; the curved surface which connects the two is not of uniform cross-section between 0—6, 0—6′, figs. 157, 158, but changes from the form shown at 6′ VI′ to that at 00′. In fig. 158 the boundary lines of the curved connecting surface are 06′VI′0′0; the plans of 06′, 0′VI′, are the circles 06, 0VI, respectively. Fig. 160 is a projection of the curved surface 0′VI′0′, where it meets the cup, and of 06′0, where it meets the strap; the latter is cut by the faces of the strap *l′m′*, *n′o′*, in the points *b′*, *c′*; an elevation of this intersection is shown at *b′h′c′*, fig. 158; the curve is not quite correct, but it is a good approximation; to draw the curve correctly would require a better knowledge of curved surfaces than we can assume the student at present possesses. If the cross-section of the curved surface was uniform, *b′h′c′* would be obtained by a construction similar to that used to obtain *ab*, fig. 137, Plate XVIII.

87. The drawing of the eccentric-rod requires no special instructions, the forked end is shown in figs. 153 to 155. Fig. 153 is a plan, fig. 152 is an elevation, and fig. 155 is a cross-section, made by the plane SP, of the chamfered portion *pq* between the fork and the cylindrical part K. Fig. 156 is a section of the pin X showing the split-pin Y.

88. **Cams.**—The motion resulting from the two arrangements just considered is of a certain fixed kind; that is to say, all cranks and ordinary eccentrics produce the same kind of irregular rectilinear motion, which motion cannot be altered, except in the case of *shifting* eccentrics. By the use of cams we can obtain any kind of rectilinear motion we choose, either regular or irregular. They are generally made in the form of discs, or grooves;

Fig. 151.

Fig. 152.

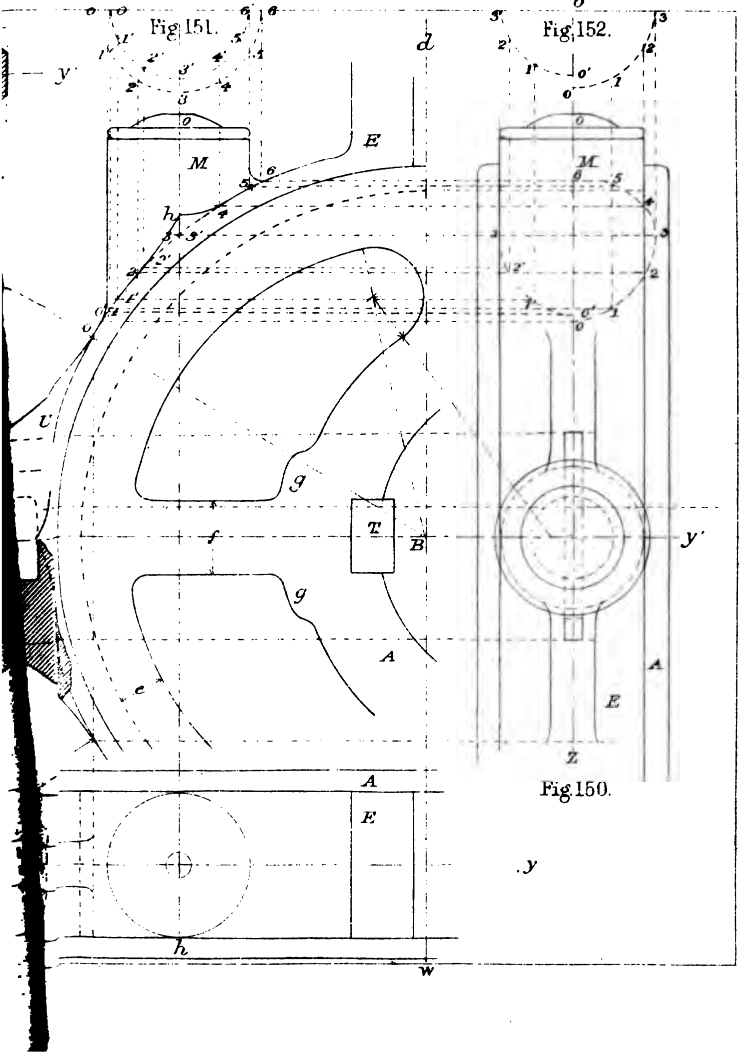


Fig. 150.

figs. 161 to 166, Plate XXIII., represent three common forms of cams. Fig. 161 shows one revolution of a *spiral*, which is used as a *base* for the cams shown in the remaining figures. Its construction is as follows:—Describe concentric circles of radii C0, C12 (3″ and 6″, respectively); divide the distance 0—12 into any convenient number of equal parts divisible by 4, say 12; and divide the circumference of the outer circle into the same number of equal parts; from these points draw radii; make one of them equal to C12, and each of the others in succession less than the preceding by $\frac{1}{12}$ of 0—12, the last one, C0, being in the same radius as C12.

Through the extremities I, II, III, &c., of these radii draw the curve; this is the required spiral. If now the spiral is centred upon C and made to rotate, having its curved surface in contact with a sliding piece at 0, which is free to move in a direction C12, then for equal arcs described by the spiral, the sliding piece will move through equal spaces; for example, if the spiral turns through an angle 2C12 ($\frac{2}{12}$ of a revolution) the sliding piece will move from 0 to 2 ($\frac{2}{12}$ of 0—12), and so on for each fraction of a revolution. The motion of the sliding piece is therefore uniform.

89. The form of cam described above can only be used for motion in one direction; but by using the one shown in fig. 162 we can obtain an alternate motion, which is also uniform. The cam in this example consists of two equal and similar halves, the distance between the two circles being divided into 6 equal parts instead of 12, while the circumference is divided into the same number as in fig. 161; this is usually called the *heart-shaped* cam. Fig. 163 is a cam for producing a regular motion, but the time occupied for the forward and backward motion is not the same, one being performed in $\frac{5}{12}$ and the other in $\frac{7}{12}$ of a revolution. Figs. 161 to 163 are drawn to a scale of $\frac{1}{16}$, figs. 164 to 166 to a scale of $\frac{1}{8}$.

90. The cams in figs. 161 to 163 are supposed to act upon *mathematical points*, which in practice is impossible, we have therefore to assign some size to the point acted upon by the cam; to illustrate this we will take a practical example and work it out. Let it be required to give to a roller A, 2″ diameter, attached to a sliding piece, and capable of moving in the direction SP, a regular alternate rectilinear motion of 6″, the distance from the centre of the cam to the centre of the roller, when at its greatest distance from C, to be 12″. Draw the centre lines *ay*, SP; from C as a centre with a radius of 12″, describe a circle cutting SP in A′; from A′ along SP towards C set off A′A = 6″, the extent of the motion; and from C as a centre with a radius CA′ describe a circle; divide its circumference into 16 equal parts, and the distance AA′ into 8 equal parts. Through the points I, II, III, &c., draw the cam shown in dotted lines, as for fig. 162; if the roller were a point, or the *knife edge* of a sliding bar, this would be the required cam; but the roller has a diameter of 2″, therefore, from the points A′, I, II, III, &c., as centres with a radius of 1″, describe arcs of circles inside the dotted cam; a curve touching these arcs will be the outer edge of the required cam.

91. The following are the dimensions of its several parts:—Thickness of rim *c* 1″; width of rim *h* 3″; diameter of shaft *a* 3″; key *g* ⅞″ × ½″, 6″ long; diameter of boss *b* 5½″, and 4½″ through; the arms *f* are ¾″ thick, and 2″ wide at the narrowest part, increasing to 2¼″ for the longest arm; the others are in the same proportion; inside the rim and outside the boss is a feather *d* ¾″ wide and ¾″ thick; on each arm there are two feathers *e* ¾″ thick and ¾″ deep, increasing to ⅞″ in the longest arm. The inside of the rim *c* and the feather *d* are curves parallel to the outside of the rim.

Fig. 164 is a front-elevation, fig. 165 is an end-elevation, and fig. 166 is a sectional end-elevation, made by the plane SP, fig. 164.

92. During one half revolution of the cam, as the radii *increase* from CD to CL, the roller is moved outwards from A to A′; but in the return half revolution the

radii *decrease* from CL to CD, it is therefore necessary to apply some means of keeping the roller in contact with the cam, which may be accomplished by means of a spring or a weight, or by using another roller B, and connecting the two with a link, so that to produce the return of the roller A the cam acts upon the roller B, and thus brings back A, together with the slide attached to it.

CHAPTER XI.

93. Inking-in a Drawing.—It is usual to put drawings of machinery in ink, whether *working* or *finished* drawings, since by constant use the blacklead lines would remain only for a very short time. Indian ink is the kind of ink used; it may be obtained either in the solid or liquid state: the former will be the best for the general student to obtain it in. Sticks of a good quality can be had for one shilling and upwards; cheaper qualities are not to be recommended. Having prepared the ink for use by rubbing it in a clean slab with a little water, and having satisfied yourself that it is of the required shade, by trying it with your drawing-pen on the margin of the drawing, commence to ink-in. But, before doing so, the following general hints will be of service to the student:—Clean off with india-rubber all surplus blacklead, leaving the lines just visible, as the lead is liable to get between the nibs of the pen, and so cause the lines to be irregular. When you have supplied the pen with ink, before using it try it on the margin of your drawing, so as to get the line of the required thickness. Never put away your pens with ink in, but clean them with a piece of wash-leather or linen rag; it will also be necessary to clean between the nibs occasionally while using the pens.

94. The following order should be observed in inking-in: —First ink-in all circles, portions of circles, and curved lines, to which straight lines are to be joined, keeping both the nibs and the needle point of the bow-pen as nearly perpendicular to the drawing board as possible; if the nibs are inclined too much to the surface of the paper the circular lines will be irregular in thickness, and if the needle point is inclined too much the hole will be enlarged, which is objectionable. The pen for drawing straight lines, or curved lines by means of moulds or curves, should be held nearly perpendicular, being inclined a little towards the right and outwards, so that the point of the pen may be seen. The lines are to be drawn from left to right, as in penciling. Particular care should be taken in joining a curve and a straight line; the best way is to commence the straight line from the curved one, and not try to join the former to the latter. If the lines of the drawing, both full and dotted, are correctly shown in pencil, it is immaterial whether the full lines are put in first and then the dotted ones, or otherwise; but if this is not the case, then begin by inking-in the lines which are *furthest from the plane upon which the view of the object is projected*, as such lines will be in full; the outline* of the object will also be in full, the remaining lines must be determined by the ordinary principles of projection.

95. The beginner should be extremely careful in inking-in his drawings, so as to avoid having to use the knife, or any other means, for scraping out or erasing a wrong line; it will therefore be advisable for him to pencil-in all lines as they are to be inked-in.

After considerable practice he may deviate a little from this order; but, as a rule, the less it is deviated from the better, as the dotted lines should be distinguished from full lines; not necessarily by dots of equal length, but just sufficient to show the difference.

96. Shade or Dark Lines.—In the examples given up to Plate XXIII., except in Plate II., we have considered

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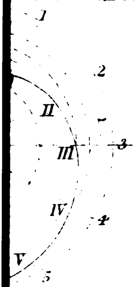
* By the term *outline* we mean the boundary lines of the object, outside of which there are no lines.



Scale 1/16

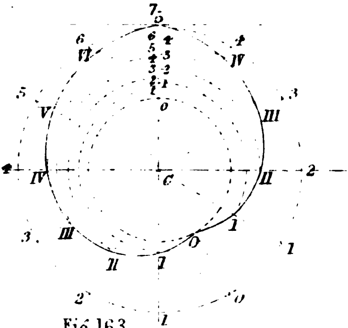


Fig. 163.

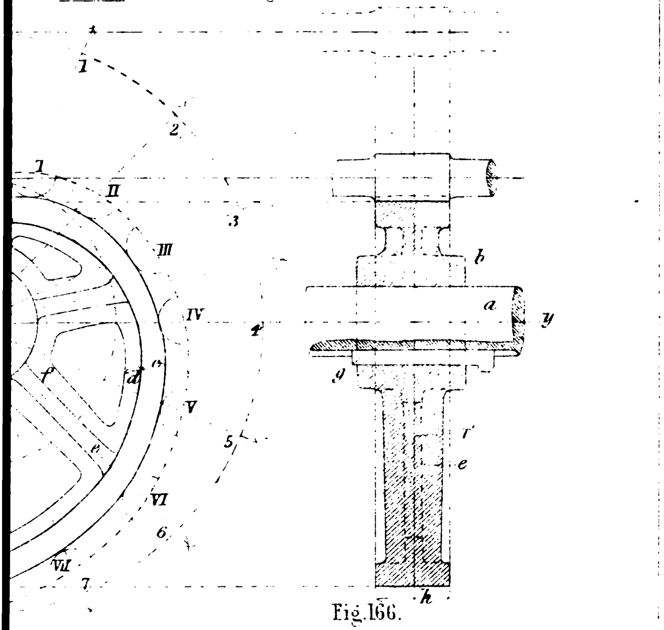


Fig. 166.

the drawings to be plain outline drawings, having all the lines, which form the boundaries of the surfaces represented in each figure, of the same thickness; we will now explain the use of *shade* or *dark lines.*

The figures in Plates XII. to XXIII. may be taken as types of those termed *working drawings,* that is, drawings from which the object is to be constructed; in such drawings all the lines are to be of the same thickness. For *finished drawings,* which are usually made to a small scale ($\frac{1}{8}$ and under) and used for the purpose of reference, &c., shade lines are often employed, whose chief use is to convey to the mind a better idea of the form of the several parts of the object, and to give what is considered by many to be, a better finish to the drawing; however, their use is a matter of taste: In Plate II. shade lines are employed. Figs. 190 to 192, Plate XXVI., represent, as a finished shade-lined drawing, the pedestal shown in Plate XXIV.

97. For the purpose of shade-lining drawings, the light is assumed as coming from the left-hand and from behind the observer towards the object, and at such an angle that the projections of each ray* are inclined to the horizontal and vertical planes at an angle of 45°.

Figs. 167, 168, are the plan and elevation of an object made up of plane surfaces, having a square hole through it. The lines *ab* represent the direction of the rays of light; those lines upon which the light falls directly are fine lines, the remainder are made thicker, and are termed *shade* or *dark lines.* We may say generally, for elevations, the shade lines are put on the *right-hand* and *bottom edges* of projecting surfaces; where two surfaces are in contact, if the upper one does not project beyond the lower one the shade line is not used, as shown in the bottom line of fig. 168; the object is supposed to be resting on a horizontal plane. In the case of sections and hollows, the shade lines are on the *left,* as shown in

* The rays are considered to be parallel.

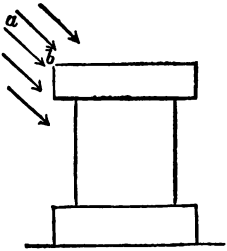


Fig. 168.

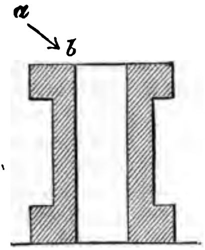


Fig. 170.

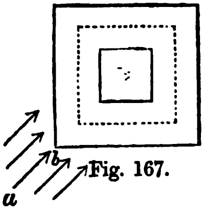


Fig. 167.

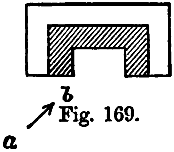


Fig. 169.

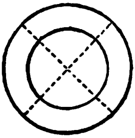


Fig. 173.

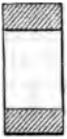


Fig. 174.

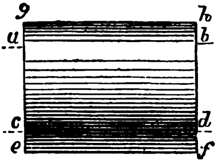


Fig. 171.

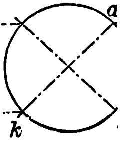


Fig. 172.

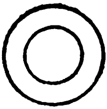


Fig. 175.

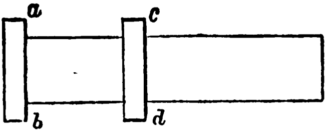


Fig. 176.

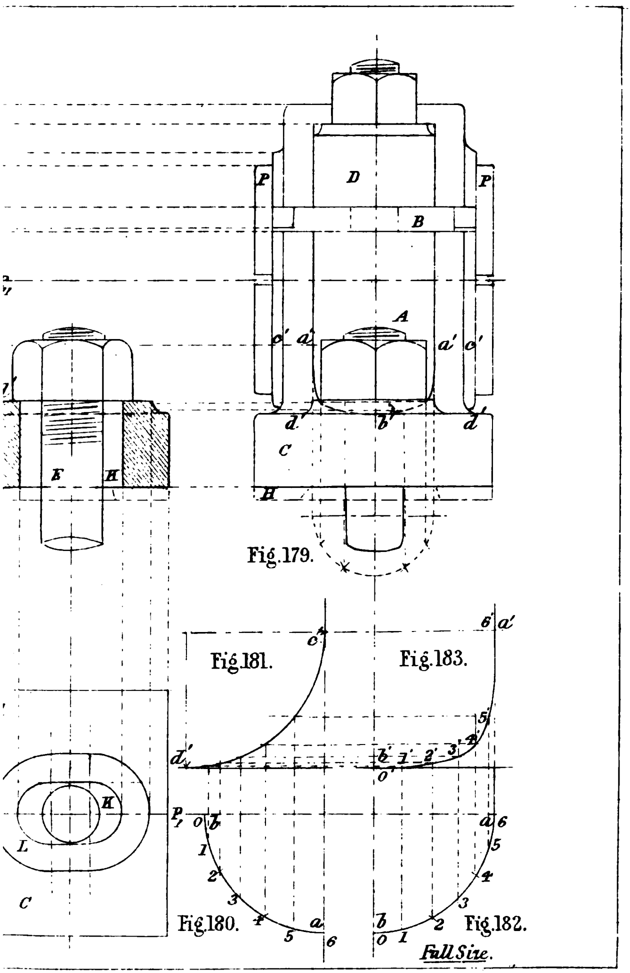


Fig. 179.

Fig. 181.

Fig. 183.

Fig. 180.

Fig. 182.

Full Size.

fig. 170. Figs. 167 and 169 show how shade lines are employed for plans, fig. 169 is a sectional plan.

98. For cylindrical objects there is a little difference in the use of shade lines. Figs. 171, 172, represent in front and end-elevation a portion of a shaft; fig. 171 is *shaded;* along the line *ab* the *light* is most intense, gradually decreasing towards *gh* and *cd*; along *cd* the *shade* is greatest, and gradually decreases towards *ab*, *ef*; if now we put a shade line for *ef* the effect which the shading produces is destroyed; for this reason shade lines are not employed for cylindrical objects,* except for the ends and projecting parts, as *fh*, fig. 171, and *ab*, *cd*, fig. 176.

The circular ends are represented as shown in figs. 172, 173, and 175, the circular line increasing in thickness from the points *a*, *k*, to *c*, fig. 172, where it is thickest. In hollow cylindrical objects the inside and outside are shade-lined, as shown in fig. 173, and sections of the same have shade lines, as shown in fig. 174.

Figs. 175, 176, represent in front and end-elevation a shaft having a neck and collars, upon which are shown the usual shade lines.

99. By a proper use of shade lines one view of the drawing of an object will convey a much better idea of the form of the object represented, than if they were not used; cylindrical forms can be distinguished from other forms by the omission of the shade line in the former; and projecting surfaces can be distinguished from other surfaces and also from recesses by the position of the shade line. Where dotted lines are used in shade-lined drawings they should be all of the same thickness.

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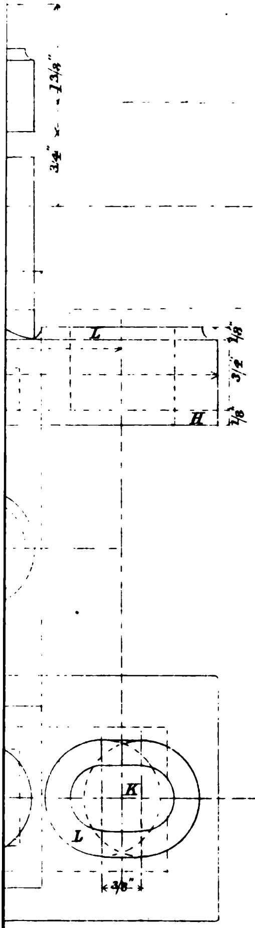
* However, if we consider the use of shade lines to be a matter of taste, and therefore liable to difference of opinion, we may state that in many cases they are used for cylindrical objects.

CHAPTER XII.

100. Working and Finished Drawings.—We will now give examples of the two chief kinds of drawings used, taking a *Pedestal* or *Plummer-Block* as the object for representation. In Plate XXIV. is shown an ordinary *working drawing* of the whole pedestal (figs. 180 to 183 are added for another purpose, as will be explained shortly); the dimensions are not given, as the parts are shown in detail in Plate XXV. The cast-iron and brass portions are shown in Plate XXV. in detail with all the dimensions added and also the radii of the arcs of circles: this may be taken as a type of drawings such as should be supplied to the *Pattern* or *Model Maker*, along with Plate XXIV., which shows the arrangement of the whole as put together. The wrought-iron work is also drawn in detail for the *Smith*. In Plate XXVI. is shown the pedestal as a *finished* shade-lined drawing.

101. Pedestal or Plummer-Block.—In Plates XXIV. to XXVI. are shown in elevations and plans, a pedestal as defined in Art. 29, page 37. Fig. 177, Plate XXIV., is a front-elevation, the right-hand half being in section, as made by a vertical plane S_1P_1, fig. 178. Fig. 178 is a plan, a portion of which is in section, as made by a horizontal plane $S_{11}P_{11}$, fig. 177; and fig. 179 is an end-elevation.

A is the *body* of the pedestal which supports the *steps* B; attached to A is the *sole-plate* or *base-plate* C, by which the pedestal is connected by bolts E to the frame of the machine, either directly, or by means of an intermediate bracket; D is the *cover* or *cap* connected to the body by the bolts F, the object of which is to keep the top step in contact with the shaft; on the top of the cap is an *oil-cup* G; the oil passes down the hole M through the step on to the shaft; to distribute the oil over the neck of the shaft, *oil-ways* N (see also figs. 188, 189, Plate XXV.) are cut in the steps. For millwright purposes there is generally



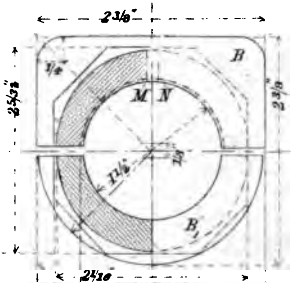


Fig. 187.

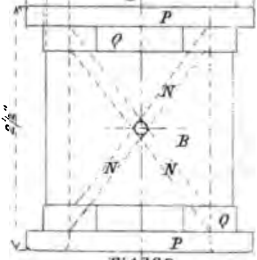


Fig. 188.

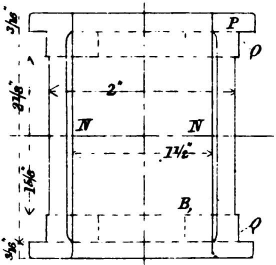


Fig. 189.

a packing of wood inserted between the base-plate and the frame, to which it is connected, as shown in Plate XXVI.; but for many purposes this lining of wood is not employed, as the object is to get a rigid connection between the pedestal and the frame, corresponding as nearly as possible to the case where the pedestal and frame are cast together. Where the wood packing is not used, the whole of the bottom surface is *planed*, or more commonly *chipping-pieces* H are cast to the base-plate, so as to reduce the amount of surface to be planed or chipped; the chipping-pieces are shown in dotted lines, their width and depth vary according to circumstances, from ¼″ to 1″ wide and ⅛″ to ½″ thick.

To allow of a slight change of position of the pedestal, and for convenience in fixing, the holes K through which the bolts E pass are elongated, as shown in fig. 178; after the exact position has been determined, pieces of hard wood or metal are inserted at the ends, between the base-plate and the *lugs* on the frame, to prevent the possibility of the pedestal moving lengthwise. The body and base-plate are made of cast-iron and are cast together, the cap is also cast-iron; the steps are usually made of brass, but the top step is often made of cast-iron; the bolts are made of wrought-iron, those for the cap are ½″ diameter, and those marked E are ⅝″ diameter. The dimensions for the body, cap, and steps, are marked on the figures in Plate XXV.; the radii of the circular arcs are also shown, which should be the case in all working drawings. On each side of the cap and body of the pedestal are facings O, whose surfaces are in contact with the *flanges* P of the steps. The body of the steps is cylindrical, but thicker at the bottom and the top than at the sides, as shown in figs. 187 to 189; chipping-pieces Q are cast at each end next to the flanges. The space between the steps is to allow of their being brought together as their inner surfaces wear; the space between the cap and the body of the pedestal is for the purpose of regulating the position of the top step.

102. The figures on Plates XXIV. and XXV. student will be able to draw without any spec instructions, excepting perhaps the curve *a'b'a'*, fig. 1 which is the intersection of the cylindrical part *aba*, 178, of the body of the pedestal with the interior of t cylindrical surface *cd*, *c'd'*. Figs. 180 to 183 show h the curve drawn full size; the method employed is simil to that used in former figures, and the construction lin show clearly how the curve is determined. If the angl at *a*, fig. 178, are filled-up, as is shown in dotted lines o the left-hand half of the figure and in fig. 191, ther would be no line of intersection, and we should have th end-elevation as represented in fig. 192.

103. In Plate XXV., fig. 184 is a front-elevation o the pedestal with the steps and bolts removed; fig. 185 is a plan of the same with the cap removed; and fig. 186 is a plan of the cap. In figs. 184, 185, we have shown the chipping-pieces H on the base-plate. The steps are shown in figs. 187 to 189; the left-hand half of fig. 187 is in section; fig. 188 is a plan of the top step, showing the oil-hole, the oil-ways N, and the chipping-pieces Q; fig. 189 is a plan of the bottom step, showing the inside in full lines. The cylindrical surfaces of the steps are not concentric, on account of the difference in the thickness of metal at the bottom and at the sides; for small steps this difference is not always taken into account, the thickness at the sides being made the same as at the bottom. Figs. 177 to 179, and 184 to 189, are drawn to a scale of $\frac{1}{2}$; figs. 180 to 183 are drawn full size.

104. The usual proportions for the several parts are as follow*:—

The diameter of the neck .... = D
Thickness of base-plate .... = D × ·3.
Thickness of cap .... = D × ·4.
Diameter of bolts (if 2 used) .... = D × ·25.
Ditto (if 4 used) .... = D × ·18.

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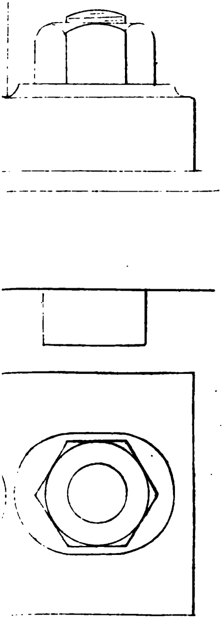
* Taken from Molesworth.



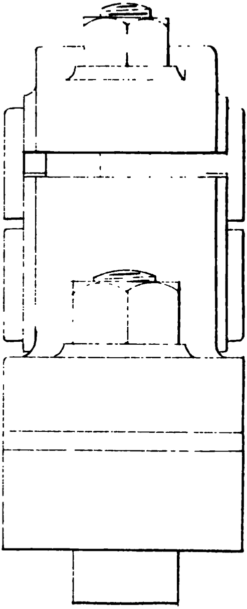


Fig.192.

Scale 1/2

STEPS.

Thickness of metal at bottom = 0·15″ + from 0·09 to 0·12 × D.
Thickness of metal at sides = ·75 of thickness at bottom.

105. In Art. 96 we stated the purpose for which *finished drawings* are usually made; there are several kinds of such drawings, but we shall confine ourselves to simple line drawings. The object for which the drawings are required must decide what kind of drawing is to be made; if there is a good scale working drawing of the whole machine, then the finished drawing may be simply an outline drawing without dotted lines, the lines may be all of the same thickness, or shade lines may be added according to taste. If however the drawing is required for general reference, then the dotted lines should be shown; the teeth of wheels should also be shown, and the centre lines omitted in all such drawings.

As an example of the former kind of finished drawings we have shown the pedestal, figs. 190 to 192, Plate XXVI. In this example shade lines are used as explained in Arts. 96 to 99. As there are no lines introduced but what have been explained, the student should have no difficulty in drawing the figures.

APPENDIX.

ALTHOUGH the student is expected to possess an elementary knowledge of Practical Geometry, we have considered it advisable to give a few examples of constructions for connecting circles and arcs of circles with straight lines, several of which are required in this book.

PROBLEM I.

To connect two given straight lines containing a right angle by means of an arc of a circle of a given radius.

Fig. 193.—Let AB, BC be the two given straight lines, and let D represent the given radius.

From B as a centre, with a radius D, cut AB, BC in E and F; through these points draw lines parallel to BC and AB respectively, intersecting in O. Then O is the centre of the required arc of circle (as the angle ABC is a right angle, the arc EF is a quadrant of a circle).

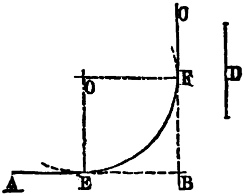


Fig. 193.

PROBLEM II.

To connect two given straight lines which meet, but do not contain a right angle, by means of an arc of a circle of a given radius.

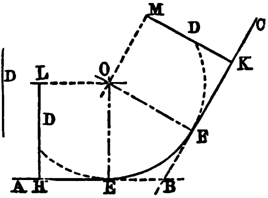


Fig. 194.

Fig. 194.—Let AB, BC be the two given straight lines, and let D represent the given radius.

In AB, BC, take any convenient points H and K, and erect perpendiculars HL and KM, equal in length to D. Through L and M draw lines parallel to AB, BC respectively, intersecting in O. Then O is the centre of the required arc of circle. From O draw OE, OF perpendicular to AB, BC respectively, then EF is the length of the arc to be drawn.

PROBLEM III.

To draw a circle to touch three given straight lines.

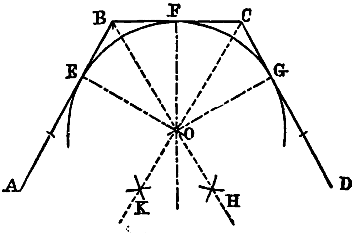


Fig. 195.

Fig. 195.—Let AB, BC, and CD be the given straight lines. Bisect the angle ABC by the line BH, the centre of the required circle will be in this line. Now bisect the angle BCD by the line CK, the centre of the required circle will be in this line also. Let BH and CK intersect in O. Then O is the centre of the required circle. From O draw perpendiculars meeting

AB, BC, and CD in E, F, and G respectively, which are the points of contact between the given lines and the circle.

PROBLEM IV.

To connect a given circle and a given straight line by means of an arc of a circle of a given radius.

a. When the given straight line passes through the centre of the given circle.

1. *To touch the given circle internally.*

Fig. 196.—Let AB be an arc of the given circle whose centre is O, CD the given straight line, and R the given radius. Draw any radius OP cutting the arc AB in E, and from E set off, inside the circle, EF equal to the radius of the connecting arc R. From O as a centre, with a radius OF, describe the arc HFK cutting the line CD. From any point L in CD draw LM perpendicular to CD, and equal in length to R. Through M draw MK parallel to CD, cutting the arc HFK in K. Then K is the centre of the connecting arc. Draw the radius KN perpendicular to CD, and from O draw the line OK, and produce it to meet AB in Q. Then NQ is the length of the connecting arc.

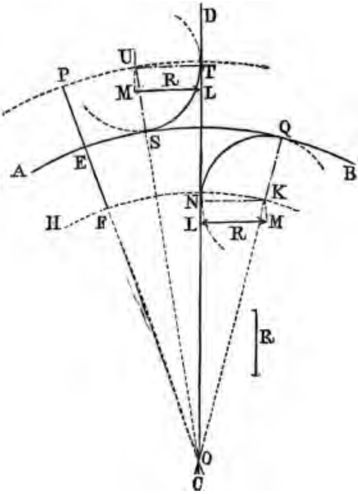


Fig. 196.

2. *To touch the given circle externally.*

The construction is shown on the left of the line CD, fig 196, and is similar to the former case; the only difference is, that the centre of the connecting arc U is outside the given circle. ST is the length of the required arc.

b. When the given straight line does not pass through the centre of the given circle.

1. *To touch the given circle externally.*

Fig. 197.—Let AB be an arc of the given circle whose centre is O, CD the given straight line, and R the given radius. Draw any radius OE and produce it, making EP equal to the given radius R. From O as a centre, with a radius OP, describe the arc PFH cutting the line CD. From any point K, in CD, draw KL perpendicular to CD, and equal in length to R. Through L draw LF parallel to CD cutting the arc PFH in F. Then F is the centre of the connecting arc. Join FO cutting AB in N, and from F draw the radius FM perpendicular to CD. Then MN is the length of the required connecting arc.

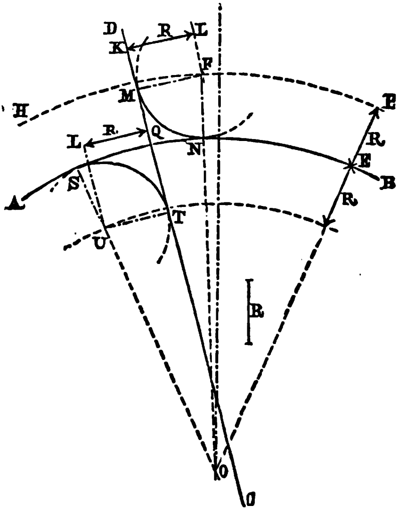


Fig. 197.

2. *To touch the given circle internally.*

The construction is shown on the left of the line CD, fig. 197.

PROBLEM V.

To describe a circle to pass through three given points.

Fig. 198.—Let A, B, and C be the three given point Join AB and BC; bisect AB and BC by the perpendicula

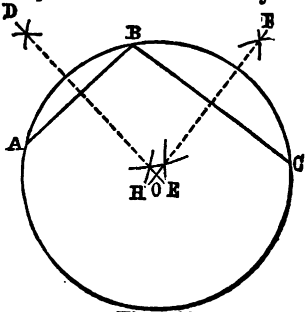


Fig. 198.

lines DE and FH, which intersect in O. Then O is th centre of the required circle, and OA its radius.

PROBLEM VI.

To draw a tangent to a given circle from a given poin

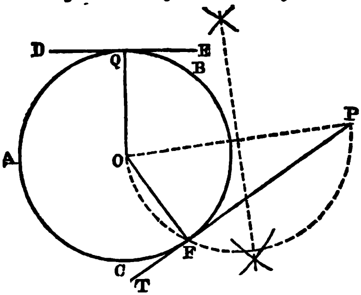


Fig. 199.

a. When the given point is on the given circle.

Fig. 199.—Let ABC be the given circle whose centre is O, and Q the given point. Join OQ, and draw DE perpendicular to OQ. Then DE is the required tangent.

b. When the given point is outside the given circle.

Fig. 199.—Let ABC be the given circle whose centre is O, and P the given point. Join PO, and upon it describe a semicircle PFO, cutting the given circle in F. Draw PT, touching the given circle in F, and it is the required tangent.

If FO is joined, PT is perpendicular to FO (the angle in a semicircle is a right angle).

PROBLEM VII.

To draw a common tangent to two given circles whose radii are unequal.

1. *To touch the given circles on the same side of the line which joins their centres.*

Fig. 200.—Let O and P be the centres of the given circles ABC and MNQ. Join OP, and let the line OP cut the given circle ABC in C. From C set off, inside

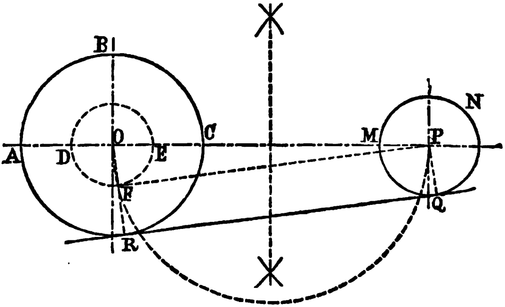


Fig. 200.

the circle, CE equal to the radius of the smaller circle MNQ. From O as a centre with a radius OE, describe the circle DEF, and from P draw a tangent PF to this circle by the construction given in the previous figure. Join OF and produce it to meet the circumference of the circle ABC in R. From P draw PQ parallel to OR, meeting the circumference of the circle MNQ in Q. Join QR, which is the required tangent.

2. *To touch the given circles on opposite sides of the line which joins their centres.*

Fig. 201.—The construction is similar to the preceding case, CE is set off outside the circle ABC instead of inside it, as in fig. 200.

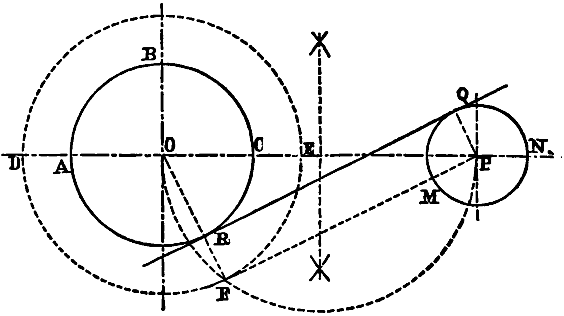


Fig. 201.

Note.—The radius of the circle DEF in fig. 200 is equal to the *difference*, and in fig. 201 it is equal to the *sum*, of the radii of the two given circles.

PROBLEM VIII.

To describe a circle which shall touch a given straight line, and also touch a given circle at a given point.

1. *To touch the given circle externally.*

Fig. 202.—Let AB be the given straight line, CDE the given circle whose centre is O, and C the given point. Join OC and produce it, from C draw ⌞CF perpendicular to OC, meeting AB in F. From F as a centre with a radius FC, describe an arc of a circle cutting AB in H. Draw HP perpendicular to AB, meeting OC produced in P. Then P is the centre of the required circle, and PH its radius.

2. *To contain the given circle.*

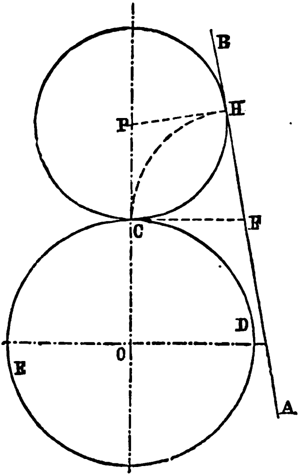


Fig. 202.

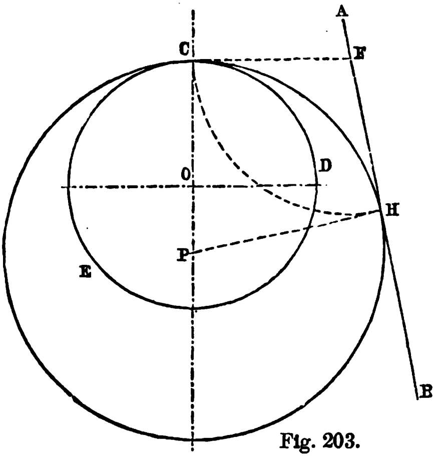


Fig. 203.

Fig. 203.—The construction is similar to the preceding

case, and, as the same letters of reference are used, the student can refer to it.

PROBLEM IX.

To describe a circle which shall touch a given circle, and touch a given straight line in a given point.

a. When the given straight line does not cut the given circle.

1. *The required circle is to touch the given one externally.*

Fig. 204.—Let CDE be the given circle whose centre is O, and F the given point in the given straight line AB. Through O draw OH perpendicular to AB, meeting the circumference of the circle CDE in H; and from F draw FQ perpendicular to AB. Join FH, cutting the circumference of the circle CDE in E. Through E draw OE, and produce it to meet the perpendicular FQ in P.

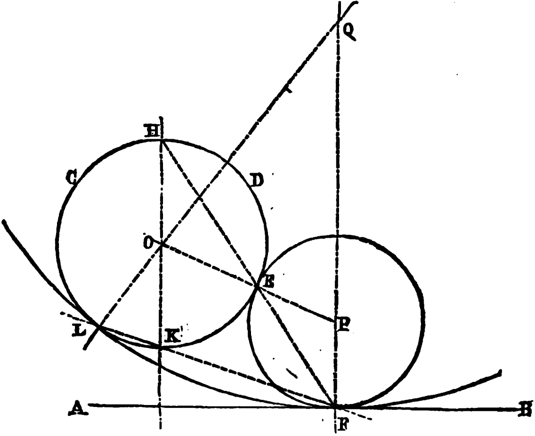


Fig. 204.

Then P is the centre of the required circle, and PE its radius.

2. *The required circle is to contain the given one.*

Fig. 204.—Let CDE be the given circle whose centre is O, and F the given point in the given straight line AB. Through O draw OK perpendicular to AB, cutting the given circle CDE in K; and from F draw FQ perpendicular to AB. Join FK, and produce it to meet the circle CDE in L. From L draw LO, and produce it to meet the perpendicular from F in Q. Then Q is the centre of the required circle, and QL its radius.

b. When the given straight line cuts the given circle.

Fig. 205.—The same construction is employed as in fig. 204, case 1.

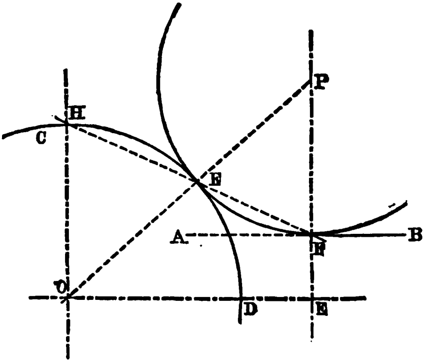


Fig. 205.

The following construction may be employed with advantage, and in many cases for drawing purposes it is more accurate.

Fig. 206.—Let CED be an arc of the given circle whose centre is O, and F the given point in the given straight line AB. Through F draw PFH perpendicular to AB, and from F set off FH, equal to the radius of the given circle CED. Join HO, and bisect it by the perpendicular PQ, cutting HP in P, and from P draw PO, cutting the given circle in E. Then P is the centre of the required circle, and PE its radius.

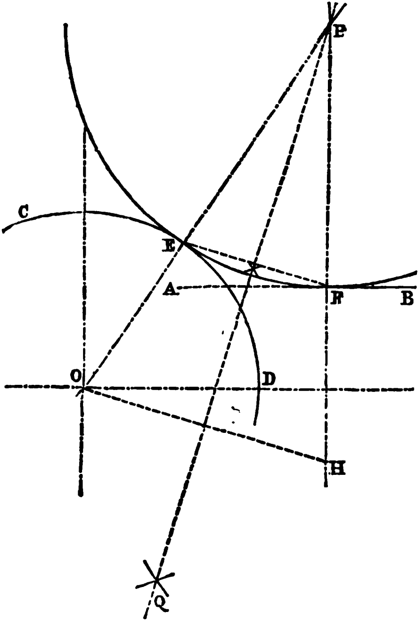


Fig. 206.

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